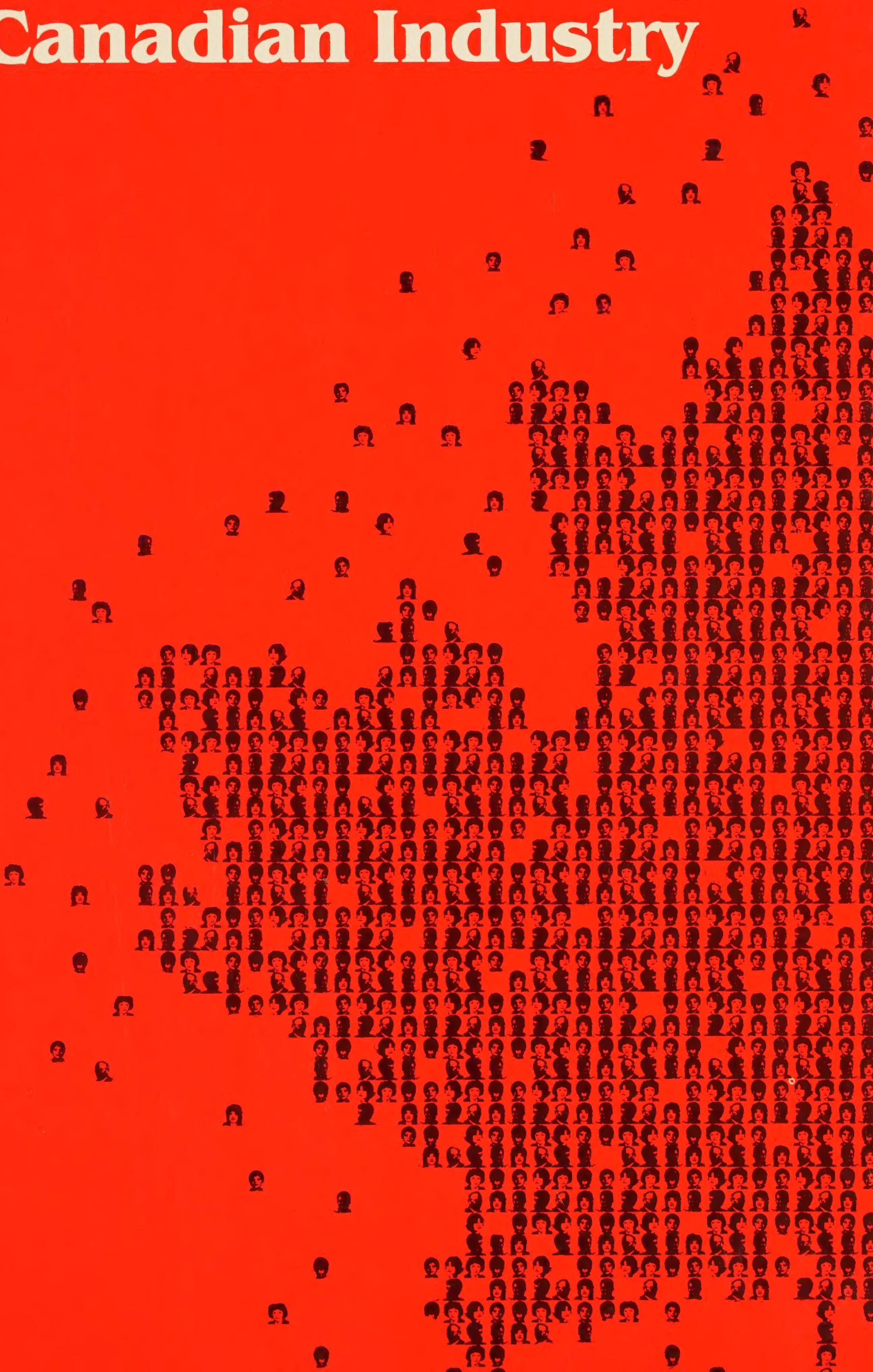
DONALD G. McFETRIDGE, Research Coordinator

Technological Change in Canadian Industry



Technological Change in Canadian Industry

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The studies contained in this volume reflect the views of their authors and do not imply endorsement by the Chairman or Commissioners.

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Research Coordinator

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Foreword

When the members of the Rowell-Sirois Commission began their collective task in 1937, very little was known about the evolution of the Canadian economy. What was known, moreover, had not been extensively analyzed by the slender cadre of social scientists of the day.

When we set out upon our task nearly 50 years later, we enjoyed a substantial advantage over our predecessors; we had a wealth of information. We inherited the work of scholars at universities across Canada and we had the benefit of the work of experts from private research institutes and publicly sponsored organizations such as the Ontario Economic Council and the Economic Council of Canada. Although there were still important gaps, our problem was not a shortage of information; it was to interrelate and integrate — to synthesize — the results of much of the information we already had.

The mandate of this Commission is unusually broad. It encompasses many of the fundamental policy issues expected to confront the people of Canada and their governments for the next several decades. The nature of the mandate also identified, in advance, the subject matter for much of the research and suggested the scope of enquiry and the need for vigorous efforts to interrelate and integrate the research disciplines. The resulting research program, therefore, is particularly noteworthy in three respects: along with original research studies, it includes survey papers which synthesize work already done in specialized fields; it avoids duplication of work which, in the judgment of the Canadian research community, has already been well done; and, considered as a whole, it is the most thorough examination of the Canadian economic, political and legal systems ever undertaken by an independent agency.

The Commission's research program was carried out under the joint direction of three prominent and highly respected Canadian scholars: Dr. Ivan Bernier (*Law and Constitutional Issues*), Dr. Alan Cairns (*Politics and Institutions of Government*) and Dr. David C. Smith (*Economics*).

Dr. Ivan Bernier is Dean of the Faculty of Law at Laval University. Dr. Alan Cairns is former Head of the Department of Political Science at the University of British Columbia and, prior to joining the Commission, was William Lyon Mackenzie King Visiting Professor of Canadian Studies at Harvard University. Dr. David C. Smith, former Head of the Department of Economics at Queen's University in Kingston, is now Principal of that University. When Dr. Smith assumed his new responsibilities at Queen's in September, 1984, he was succeeded by Dr. Kenneth Norrie of the University of Alberta and John Sargent of the federal Department of Finance, who together acted as Co-directors of Research for the concluding phase of the Economics research program.

I am confident that the efforts of the Research Directors, research coordinators and authors whose work appears in this and other volumes, have provided the community of Canadian scholars and policy makers with a series of publications that will continue to be of value for many years to come. And I hope that the value of the research program to Canadian scholarship will be enhanced by the fact that Commission research is being made available to interested readers in both English and French.

I extend my personal thanks, and that of my fellow Commissioners, to the Research Directors and those immediately associated with them in the Commission's research program. I also want to thank the members of the many research advisory groups whose counsel contributed so substantially to this undertaking.

DONALD S. MACDONALD

Introduction

At its most general level, the Royal Commission's research program has examined how the Canadian political economy can better adapt to change. As a basis of enquiry, this question reflects our belief that the future will always take us partly by surprise. Our political, legal and economic institutions should therefore be flexible enough to accommodate surprises and yet solid enough to ensure that they help us meet our future goals. This theme of an adaptive political economy led us to explore the interdependencies between political, legal and economic systems and drew our research efforts in an interdisciplinary direction.

The sheer magnitude of the research output (more than 280 separate studies in 70+ volumes) as well as its disciplinary and ideological diversity have, however, made complete integration impossible and, we have concluded, undesirable. The research output as a whole brings varying perspectives and methodologies to the study of common problems and we therefore urge readers to look beyond their particular field of interest and to explore topics across disciplines.

The three research areas, — *Law and Constitutional Issues*, under Ivan Bernier; *Politics and Institutions of Government*, under Alan Cairns; and *Economics*, under David C. Smith (co-directed with Kenneth Norrie and John Sargent for the concluding phase of the research program) — were further divided into 19 sections headed by research coordinators.

The area *Law and Constitutional Issues* has been organized into five major sections headed by the research coordinators identified below.

- Law, Society and the Economy — *Ivan Bernier and Andrée Lajoie*
- The International Legal Environment — *John J. Quinn*
- The Canadian Economic Union — *Mark Krasnick*

- Harmonization of Laws in Canada — *Ronald C.C. Cuming*
- Institutional and Constitutional Arrangements — *Clare F. Beckton and A. Wayne MacKay*

Since law in its numerous manifestations is the most fundamental means of implementing state policy, it was necessary to investigate how and when law could be mobilized most effectively to address the problems raised by the Commission's mandate. Adopting a broad perspective, researchers examined Canada's legal system from the standpoint of how law evolves as a result of social, economic and political changes and how, in turn, law brings about changes in our social, economic and political conduct.

Within *Politics and Institutions of Government*, research has been organized into seven major sections.

- Canada and the International Political Economy — *Denis Stairs and Gilbert Winham*
- State and Society in the Modern Era — *Keith Banting*
- Constitutionalism, Citizenship and Society — *Alan Cairns and Cynthia Williams*
- The Politics of Canadian Federalism — *Richard Simeon*
- Representative Institutions — *Peter Aucoin*
- The Politics of Economic Policy — *G. Bruce Doern*
- Industrial Policy — *André Blais*

This area examines a number of developments which have led Canadians to question their ability to govern themselves wisely and effectively. Many of these developments are not unique to Canada and a number of comparative studies canvass and assess how others have coped with similar problems. Within the context of the Canadian heritage of parliamentary government, federalism, a mixed economy, and a bilingual and multicultural society, the research also explores ways of rearranging the relationships of power and influence among institutions to restore and enhance the fundamental democratic principles of representativeness, responsiveness and accountability.

Economics research was organized into seven major sections.

- Macroeconomics — *John Sargent*
- Federalism and the Economic Union — *Kenneth Norrie*
- Industrial Structure — *Donald G. McFetridge*
- International Trade — *John Whalley*
- Income Distribution and Economic Security — *François Vaillancourt*
- Labour Markets and Labour Relations — *Craig Riddell*
- Economic Ideas and Social Issues — *David Laidler*

Economics research examines the allocation of Canada's human and other resources, the ways in which institutions and policies affect this

allocation, and the distribution of the gains from their use. It also considers the nature of economic development, the forces that shape our regional and industrial structure, and our economic interdependence with other countries. The thrust of the research in economics is to increase our comprehension of what determines our economic potential and how instruments of economic policy may move us closer to our future goals.

One section from each of the three research areas — The Canadian Economic Union, The Politics of Canadian Federalism, and Federalism and the Economic Union — have been blended into one unified research effort. Consequently, the volumes on Federalism and the Economic Union as well as the volume on The North are the results of an interdisciplinary research effort.

We owe a special debt to the research coordinators. Not only did they organize, assemble and analyze the many research studies and combine their major findings in overviews, but they also made substantial contributions to the Final Report. We wish to thank them for their performance, often under heavy pressure.

Unfortunately, space does not permit us to thank all members of the Commission staff individually. However, we are particularly grateful to the Chairman, The Hon. Donald S. Macdonald; the Commission's Executive Director, J. Gerald Godsoe; and the Director of Policy, Alan Nymark, all of whom were closely involved with the Research Program and played key roles in the contribution of Research to the Final Report. We wish to express our appreciation to the Commission's Administrative Advisor, Harry Stewart, for his guidance and advice, and to the Director of Publishing, Ed Matheson, who managed the research publication process. A special thanks to Jamie Benidickson, Policy Coordinator and Special Assistant to the Chairman, who played a valuable liaison role between Research and the Chairman and Commissioners. We are also grateful to our office administrator, Donna Stebbing, and to our secretarial staff, Monique Carpentier, Barbara Cowtan, Tina DeLuca, Françoise Guilbault and Marilyn Sheldon.

Finally, a well deserved thank you to our closest assistants: Jacques J.M. Shore, *Law and Constitutional Issues*; Cynthia Williams and her successor Karen Jackson, *Politics and Institutions of Government*; and I. Lilla Connidis, *Economics*. We appreciate not only their individual contribution to each research area, but also their cooperative contribution to the research program and the Commission.

IVAN BERNIER
ALAN CAIRNS
DAVID C. SMITH

Preface

The papers in this volume of the Commission's research series discuss the sources, rate and nature of technological change and its effect on Canadian industry. These papers focus on four principal major issues:

- Canada's international position as a producer and user of new technology;
- the determinants and consequences of Canadian R&D spending;
- the diffusion of technology both globally and within Canada; and
- the evolution and current state of North American management technique.

Other aspects of technological change are examined in other volumes of research studies prepared for the Royal Commission. Analyses of Canadian productivity growth, experience and prospects are provided in volume 22 by M.G.S. Denny and by John Helliwell, Mary MacGregor and Tim Padmore. The impact of technological change on employment and wages is discussed in an historical context by Robert Allen in volume 18. The evidence on factors contributing to the adaptability of workers and managers to technological change is summarized by Steven Globerman, also in volume 18.

The essential concern of this volume is with the technological and managerial aspects of the organization of production. Other aspects of the organization of production including corporate ownership and concentration, and plant size and specialization are covered in *Canadian Industry in Transition*, volume 2 of the research series.

The first paper in the present volume is by Jeffrey I. Bernstein, who examines both the consequences of industrial R&D spending and its

environmental determinants. With respect to the consequences of R&D, Bernstein rightly emphasizes the attempts which have been made to estimate private and social rates of return on R&D. Most economists would advocate that government support for R&D be guided by the criterion of equalizing private and social rates of return rather than by adherence to a target ratio of R&D to gross national product.

Bernstein finds that estimates of the private rate of return on R&D in Canada are quite high, ranging from 20 to 60 percent. He also cites evidence of large spillover benefits both to the users of products embodying R&D and to the competitors of R&D performers. The implication is that the social rate of return on R&D is well in excess of the private rate of return and that government support is warranted on efficiency grounds. The high private rates of return cited may also justify assistance if the risk premium they imply exceeds the social cost of risk-bearing. With respect to the determinants of R&D, Bernstein cites important recent findings, many of them his own, to the effect that both R&D and investment tax incentives have a significant impact on private R&D spending. On the basis of this evidence, tax incentives would have to be regarded as the superior form of R&D support.

Ned Ellis and David Waite make use of data on patents to measure the stability of the industrial pattern of inventive activity, the extent to which Canadian inventors are represented in active or growth technologies (biotechnology, fibre optics, etc.) and changes in Canada's relative importance internationally both as a source and as a destination for new technologies.

They find that the pattern of technological change is erratic and difficult to predict, that Canada lies in the middle of industrial nations in terms of its representation in active technologies and that Canada is marginal both as a source of patented inventions and as a place for foreigners to patent and that its status in this regard has deteriorated slightly in recent years.

Edwin Mansfield devotes most of his attention to an assessment of evidence respecting the rate, mode and pattern of international diffusion of new technologies. He finds that new technologies today tend to be transferred abroad both sooner after their initial introduction and more often than was the case twenty years ago. Although the newest technologies tend to be transferred within multinational enterprises, there has been a general trend toward arm's-length transfers. Japan has emerged as second only to the United States as a source of innovation, and even the innovations of U.S. firms are no longer necessarily introduced first in the United States. Canada has tended to acquire new technologies earlier than most countries, but this position is eroding. Mansfield advocates the maintenance of a favourable macroeconomic climate rather than detailed intervention into innovative activity as the best way for the government to ensure continued high rates of innovation.

Donald Lecraw examines the state of contemporary North American management techniques. He assesses recent arguments to the effect that Japanese firms are better managed because they utilize more modern methods and focus more on productivity and quality and less on finance, litigation and paper entrepreneurialism than North American firms.

Lecraw concludes that while many U.S. firms have not performed well in recent years, the market mechanism can be relied upon to force an improved performance where necessary and to the extent that general economic conditions allow. Lecraw is somewhat less optimistic about Canadian firms, detecting in them some evidence of unwillingness or inability to embrace new methods or seek new opportunities.

Isaiah Litvak and Christopher Maule study the approach of management to technical change, productivity improvement and corporate strategy of the major firms in the aluminum and steel industries, all of which have been highly successful. In these firms the benefits of a managerial emphasis on production and productivity and an avoidance of conglomerate diversification are especially evident.

Donald G. McFetridge and Ronald J. Corvari survey the literature on the diffusion of new technologies within Canada and on related public policies. They find that existing studies provide some evidence that new technologies diffuse more slowly within Canada than within some other countries but that the public policy response in the form of technology centres and transfer programs has been out of proportion to the magnitude of the problem. With regard to the often debated issue of support for R&D versus support for technology acquisition, they conclude that the excess of the social over the private rate of return on technology acquisition — and hence the desirable level of government assistance — is probably smaller than is the case with R&D.

D.G. McFetridge

Acknowledgments

The Research Advisory Group on the Economics of Industrial Structure played an important role in the development of the material presented in this volume. Their contributions are gratefully acknowledged. Members of the Group were John R. Baldwin, Léon Courville, Donald J. Daly, Dennis P. De Melto, Steven Globerman, Paul Gorecki, Christopher Green, Richard G. Harris, Donald Lecraw, George Lermer, Frank Mathewson, and Michael Trebilcock.

D.G.M.

Research and Development, Patents, and Grant and Tax Policies in Canada

JEFFREY I. BERNSTEIN

Product and process developments have begun to occupy the centre stage in discussions relating to production activities. Indeed, technological change appears to be the cure for such diverse ills as inadequate output growth, fierce foreign competition, low productivity levels, and income disparities. However, no cure exists without side effects. Recent fears have surfaced concerning the level of unemployment and the skill composition of the labour force in the face of continually high rates of technological change. The significance of these issues in affecting individual well-being has led governments to introduce a wide variety of policies designed to influence product and process development.

Research and development (R&D) investment projects comprise a major element of the resources devoted to technological development. This has caused governments to focus their policy instruments on the rate and direction of R&D investment. As Canada entered the 1980s, there was a deep concern that R&D expenditures were inadequate to sustain the desired rate of technological change. The most frequently cited evidence in support of this view is a comparison of Canadian R&D expenditures with those in other developed countries. Table 1-1 shows that the ratio of R&D expenditures to gross domestic product (GDP) for Canada is substantially below that of its major trading partners.

Although the appropriateness of this broad measure of the adequacy of Canadian resources dedicated to product and process development can be questioned, governments at both the federal and provincial levels have decided that assistance is necessary. At the federal level, policies have included the provision of technical information, tax incentives, grants and procurement from the private sector. These policies have been modified and intensified over the years.

TABLE 1-1 Research and Development Expenditures as a Percentage of Gross Domestic Product, Selected Years 1973–79

	1973	1975	1977	1979
Canada	1.12	1.11	1.07	1.12
France	1.78	1.80	1.76	1.82
Germany	2.09	2.22	2.14	2.27
Japan	1.87	1.94	1.91	2.04
Netherlands	2.01	2.12	1.99	1.98
Sweden	1.60	1.75	1.87	1.89
Switzerland	2.25	2.40	2.29	2.45
United States	2.50	2.44	2.39	2.41

Source: Statistics Canada, "R&D Expenditures in Canada 1963–1983," background document no. SS1983–5, prepared in conjunction with SC Cat. No. 13–212.

There are two major objectives of this paper. The first purpose is to discuss and analyze the evidence relating to the interrelationship between product and process development and production activities. This task is carried out in two stages. The first characterizes the conceptual framework through which to view the role of technological development. This is undertaken within the context of corporate decisions regarding production and investment programs. Also discussed are the measurement problems associated with the indicators reflecting the resources allocated to product and process development.

The second stage pertains to a survey and evaluation of the empirical evidence on the consequences and causes of product and process development. Discussion focusses on the influence that R&D investment exerts on output and productivity growth in the Canadian and U.S. economies. Also analyzed is the manner in which R&D investment and inventive output are influenced by factor prices and sales. These empirical findings emphasize that the accumulation of R&D investment and the production of inventive output are intrinsic components and are jointly determined within the complete array of corporate production and investment decisions.

The second objective of this paper is to evaluate the effects of federal government policies on the rate of R&D investment. The stimulating influences and the costs of grants and tax incentives are discussed. Moreover, the tax incentives are decomposed. The R&D investment tax credit, the tax allowance, and the measures designed to increase the utilization of the credits are each evaluated.

Product and Process Development

Firms operating in many diverse industries undertake investment and utilize factors of production in order to develop new products and production techniques. In general, resources are allocated such that new products offer customers what they need more inexpensively.

This section covers the issues regarding allocation decisions relevant to product and process development. The conceptual framework relating to the production and investment decisions associated with developing new products and processes and the measurement problems associated with analyzing them are described.

The Conceptual Framework

Economists generally view the development of new products and production processes as part of the production activities of a firm, industry, region, or country. These activities involve inputs ranging through various types of labour, physical capital, and materials which are transformed into outputs.

The framework is even more detailed because product and process development is embedded into the complete set of production activities. As Mansfield et al. (1971) note, "The effectiveness of a firm's R&D department depends heavily on its relations with other parts of the firm" (p. 10). There are many instances where ideas have emerged and have not been put to use because their significance was not grasped. Conversely, there are situations where there have been difficulties in organizing the scientific and engineering effort into creating operative products and processes. Conceptually, the view is quite straightforward: there is a general production relationship for a firm (or industry, region or country) which transforms inputs into outputs. Some of these outputs pertain to product and process development. These outputs are created from inputs which may be used simultaneously to produce many different outputs, while some factors may be dedicated solely to the development of new products and processes. Thus, one need not think of product and process development as being carried out independently or separately from other production activities. Instead, there is joint production.[1]

The multiplicity of inputs used in the creation of new products and processes forces the introduction of aggregations in order to determine statistically the causes and consequences of these activities. Usually scientists and engineers, laboratories, and associated equipment are grouped into a single or a few broad input categories. These are referred to as the knowledge capital or R&D capital inputs (see Griliches, 1979, and Bernstein and Nadiri, 1984). It is important to recognize that these knowledge capital inputs may be utilized jointly to alter (to various degrees) product characteristics or to develop new processes.

The output of product and process developments are generally aggregated into two categories called invention and innovation. Invention is a prescription for a new product or process. Sometimes there is the added requirement that the product or process must be useful as well as novel. Inventions can occur in different ways. The attempt to soive a particular problem may result in solutions to completely different problems. For

example, the most important plastic material was not deliberately sought but was the unintended outcome of other research. The links between chemistry and the plastic material polyethylene are documented by Allan (1967). Polyethelene, unlike other plastic materials, does not owe its discovery to work on the structure and synthesis of long-chain molecules, but rather to research on high-pressure reactions. Moreover, the discovery emerged by chance in 1933, when a defective apparatus led to the polymerization of ethylene. The implication is that outputs relating to product and process developments quite often turn out in reality to arise from joint production situations. In a sense, the joint production phenomenon can provide a justification for the invention and innovation distinction first introduced by Schumpeter (1966). An innovation refers to a new product or process which is actually integrated into the existing production framework of the firm. An invention may lead to an innovation, but not necessarily.[2]

There are a number of issues associated with the R&D capital accumulation, invention, and innovation decisions. First, current changes in production processes and new products are the outcome of past investment expenditures. This implies that lags exist in the development of new products and production techniques and that there is an adjustment process, which can extend over several years.

Next, new production techniques lead firms to expand output and to alter the proportions of the various inputs utilized in the production process. Certain factors may be substituted (at least in part) for other inputs used in the more expensive and superseded process. There are numerous examples where unskilled labour has been replaced by new or improved equipment.

Third, product development affects the demand conditions facing firms. Suppose that products deliver characteristics to consumers. For example, individuals demand warmth, style, and comfort from overcoats. Overcoats are the products, while warmth, style, and comfort are the characteristics. If product development or differentiation by a firm enhances the characteristics valued by customers (for example, through overcoats made of new material which provides more warmth), then revenues increase.

These adjustment, expansion, substitution, and differentiation issues are problems which are not specific to product and process development. They are associated, to various degrees, with all forms of capital accumulation and product variety. A distinctive feature, however, is the problem of appropriability.[3] Firms which produce inventive output and which innovate may not be able to exclude others in society from freely obtaining the benefits of the invention or innovation. This implies that an inventor or innovator who is not able to prevent free-riding may receive an insufficient return on the investment. The incentive to undertake R&D investment is diminished because the originator cannot appropriate all

the benefits, and society may have an inadequate level of process or product development.

It is important to clarify the notion of spillover or externality. For example, when a firm purchases physical capital, embodied in that capital is the innovation undertaken by the selling firm. This capital is part of the input requirements of the purchasing firm, and any capital improvements are reflected in the market price of the physical capital. If these prices fully reflect the benefits of the R&D investment, then no spillover has occurred. In this example, spillovers exist only to the extent that the market prices do not completely reflect the benefits from the innovation.

Spillovers are the ideas borrowed by one firm from the knowledge of another firm. Spillovers do not have to be related to input purchase flows. The telecommunications equipment industry and the computer manufacturing industry may not buy much from each other, but they may be undertaking similar R&D investment and hence benefiting from each other's inventions and innovations. Spillovers can arise from any market or, for that matter, any non-market transaction. For example, spillovers may occur when other firms' patents are used. The royalty may not reflect the social value of the patent, since rivals can patent around the ideas of the patentee. Also, spillovers are caused by the use of innovations through cross-licensing agreements. In addition, spillovers can occur between firms which do not in fact transact with each other. For example, the mobility of scientists and engineers generates knowledge investment spillovers, to the extent that the knowledge is not firm-specific, and the wage rate does not completely reflect the social value of the engineer or scientist. Thus, spillovers originate from innovations, inventions, and the knowledge capital inputs of a firm. The externalities find their way throughout the economy by various means, such as by purchasing products, using patented inventions, entering into contractual agreements on innovations, and hiring factors of production.[4]

Spillovers, by their nature, are intimately related to the spread of knowledge throughout industries and economies. They provide a source of the linkages through which the diffusion of technological change occurs. As Daly (1979) emphasizes and as Denison (1967) writes:

> Advances of knowledge differ from other growth sources in one highly important respect. . . . Secrets are few and temporary. By accelerating its own contribution to advances of knowledge, one industrialized country cannot expect to gain more than a temporary advantage over the others with respect to knowledge available for use. . . .(p. 280)

Mansfield (1968, ch.7) investigates the rate of imitation in four industries including bituminous coal, iron and steel, brewing, and railways. In each industry, he studies three innovations. The innovations from the

bituminous coal industry are the shuttle car, trackless mobile loader, and continuous mining machine; from iron and steel, they are the by-product coke oven, continuous wide-strip mill, and continuous annealing line for tin plate; in brewing, the innovations are the pallet-loading machine, tin container, and high speed bottle filler; and in railways, they are the diesel locomotive, centralized traffic control, and retarders.

Mansfield's results are generated, in part, by the existence of an externality. The number of firms that adopt an innovation within an industry depends on the proportion of firms in the industry which have already introduced it into their production process. Thus, the diffusion of technological change depends on the extent to which the technological linkages have already been established. This hypothesis can be stated in an alternative way. The rate at which knowledge spreads is related to the size of the knowledge pool. Mansfield finds that diffusion could be a rather slow process. For example, from the date of the first successful commercial application, major firms took 20 years or more to install centralized traffic control, car retarders, by-product coke ovens, and continuous annealing. However, the rate of imitation varied among industries and among innovations. Indeed, the number of years elapsing before half the firms in an industry had introduced an innovation ranged from 0.9 to 15, with an average time span of 7.8 years.[5]

Measurement of R&D Capital

R&D capital is the aggregation of inputs related to product and process development. There are two problems pertaining to the measurement of this factor of production. The first concerns the components of the input and the second involves its construction.

The components of R&D capital are derived from the data on R&D expenditures. In current statistical summaries, scientific and technological activities are defined as those activities required for the generation, dissimination, or initial application of new scientific and technological knowledge. These activities are subdivided into categories — scientific research, and experimental development and related scientific activities. The former is defined as creative work undertaken on a systematic basis to increase the stock of knowledge and to use this knowledge as new applications. Examples encompass the development of new methods of identifying tree species or the investigation of the factors determining regional variations in unemployment. The activities relating to the latter category are scientific data collection, information services, testing, feasibility, and policy studies.

R&D expenditures on scientific research and experimental development consist of the wages and salaries of scientists and engineers, the cost of laboratories, and associated equipment utilized in scientific and technological activities. In particular, R&D expenditures are classified

into current and capital expenditures. The current category consists of two groups — wages and salaries, and other. The capital category is comprised of land, building, and equipment. Current expenditures generally make up about 85 percent of R&D expenditures, with the majority arising from wages and salaries.[6]

R&D expenditures in Canada from 1971 to 1981 are presented in Table 1-2. During the decade, the expenditures in current dollars increased by about 223 percent, compared with an increase in 1971 dollars of more than 31 percent. Notice that gross domestic expenditure on R&D (GERD) in 1971 dollars did not increase monotonically over the decade. There was a slight decrease of about 1.5 percent during 1971–76, and then an increase in 1971 dollars of about 33 percent during 1976–81. An even more pronounced decline is seen in the proportion of GERD to gross domestic product (GDP), which represents the average propensity to spend on R&D. The average propensity fell from a high in 1971 to 1.36 percent to a low in 1976 of 1.06 percent. This amounted to a 22 percent decrease. The average propensity began to increase during the last half of the decade, so the decline over the whole decade was about 6 percent.

The total value of R&D does not highlight the spread of the activities throughout the Canadian economy. Table 1-3 illustrates the breakdown of R&D by sector. Expenditure in each sector increased over the period 1971–81. The government sector's R&D expenditures grew by 163 percent and the non-government sector expanded by 251 percent. The government composition of R&D was 31 percent in 1971, compared with 25 percent in 1981. Hence, R&D expenditures grew at a more rapid rate for the non-government sectors.

An examination of the composition of the non-government sector shows that the business enterprise sector comprised 51 percent of R&D expenditures in 1971 and 63 percent in 1981. This compares with 48 percent and 36 percent spent in those years for higher education. Clearly, the growth in non-government R&D expenditures is due to the growth arising from business enterprises.

The regional distribution of GERD is presented in Table 1-4. The distribution has been relatively stable. During the late 1970s, Ontario accounted for half of all R&D expenditures, followed by Quebec and the western provinces with 22 percent each, and lastly the Atlantic provinces with 6 percent. Within each region during the late 1970s, there were some interesting variations in GERD as a percentage of gross provincial expenditure (GPE). The Atlantic provinces showed a steady increase between 1977 and 1979, although it fell by 12 percentage points in 1980 before levelling off in 1981. Quebec exhibited a monotonically increasing percentage of GERD as a share of GDP. This was similar to the experience in the western provinces, although there was a decrease in 1979. Ontario also had an increasing share over the last half of the 1970s, achieving an increase of 13 percentage points in 1981, making it the region

TABLE 1-2 R&D Expenditures in Canada, 1971–82

	GERD in Current Dollars	Implicit Price Index[a]	GERD in 1971 Dollars	GDP in Current Dollars	GERD/GDP
		($ millions)			(percent)
1971	1,315	100.0	1,315	96,961	1.36
1972	1,349	105.0	1,285	108,780	1.24
1973	1,448	114.6	1,299	128,164	1.13
1974	1,694	132.1	1,282	151,570	1.12
1975	1,910	146.3	1,306	170,681	1.12
1976	2,079	160.2	1,298	195,774	1.06
1977	2,326	171.5	1,356	215,066	1.08
1978	2,629	182.4	1,441	238,465	1.10
1979	2,988	201.3	1,484	265,912	1.12
1980	3,527	222.7	1,584	291,885	1.21
1981	4,244	246.3	1,723	331,338	1.28

Source: Statistics Canada, "R&D Expenditures in Canada 1963–1983," 83–5. Background document no.SS1983–5, prepared in conjunction with SC Cat. No. 13–212.
a. GERD = gross domestic expenditure on R&D.
b. Relates to GNP.

with the highest average. Ontario has consistently been the major region in terms of both total and average propensity to undertake R&D.

The business enterprise sector is a significant contribution to R&D activities in Canada. Table 1-5 shows the breakdown of contributions to industrial R&D among mines and wells, manufacturing and services. Manufacturing comprises the major proportion of industrial R&D with 83 percent in 1974 and 78 percent in 1981. Mines and wells accounted for only 5 percent in 1974 but this percentage grew to 10 percent by 1981. Indeed, in 1981 mines and wells exhibit almost the same percentage of industrial R&D as services. In 1974, services comprised 12 percent, which was more than double the share for mines and wells.

The second measurement problem concerns construction of a knowledge or R&D capital input index. There are two possible approaches. First, it could be constructed from data on the services of the elements comprising the index (such as scientists, engineers, and laboratories) and the rental rates for these services. In this case, the knowledge capital input is defined as the services from the knowledge capital stock, with services compensated at rental rates. This is similar to defining the labour input as the services from the labour force, with labour services compensated at the wage rates. Thus, a possible approach to the construction of the knowledge capital input would be to gather data on lease transactions in the knowledge capital services.

Little work has been done on the compilation of data from lease transactions. Therefore, an alternative measurement method may be used. This approach consists in computing the level of the knowledge capital stock at each point in time from data on R&D investment flows.

TABLE 1-3 Amount and Share of R&D Expenditures by Sector, 1971–81

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
						($ millions)					
Total government	407	445	485	553	592	647	702	781	800	919	1,071
Federal	368	399	430	485	520	565	608	683	686	780	913
Provincial	39	46	55	68	72	82	94	98	114	139	158
Total non-government	908	904	963	1,141	1,318	1,432	1,624	1,848	2,189	2,608	3,173
Business enterprise	464	459	503	613	700	755	857	1,007	1,269	1,564	2,004
Higher education	436	436	450	517	606	664	750	821	898	1,019	1,138
Private non-profit	8	9	10	11	12	13	17	20	22	25	31
Total	1,315	1,349	1,448	1,694	1,910	2,079	2,326	2,629	2,988	3,527	4,244

Source: Statistics Canada, "R&D Expenditures in Canada 1963–1983," background document no.SS1983–5, prepared in conjunction with SC Cat. No. 13–1212.

TABLE 1-4 Amount and Distribution of R&D Expenditures, by Region, 1977–81[a]

	Atlantic	Quebec	Ontario	Western	Canada
			(millions of dollars)		
1977	123	451	1,046	410	2,050
1978	141	515	1,148	515	2,342
1979	182	591	1,321	581	2,689
1980	161	665	1,615	728	3,187
1981	179	812	1,935	905	3,864
			(percent)		
1977	6	22	51	20	100
1978	6	22	49	22	100
1979	7	22	49	22	100
1980	5	21	51	23	100
1981	5	21	50	23	100
			(percent of gross provincial expenditure)		
1977	0.99	0.89	1.25	0.61	0.96
1978	1.02	0.92	1.26	0.68	0.99
1979	1.13	0.95	1.29	0.65	0.99
1980	1.00	0.96	1.42	0.71	1.06
1981	0.96	1.04	1.49	0.78	1.12

Source: Statistics Canada, "R&D Expenditures in Canada 1963–1983," background document no. SS1983–5 prepared in conjunction with SC Cat. No. 13–212.
a. Pertains to Natural Science and Engineering.

TABLE 1-5 R&D Expenditures Disaggregated by Industry, 1974–81

	1974	1975	1976	1977	1978	1979	1980	1981
				($ millions)				
Industry:								
Mines and Wells	31	47	42	50	56	118	141	205
Manufacturing	509	561	604	668	791	984	1,213	1,556
Services	74	92	109	139	160	168	210	243
Total	613	700	755	857	1,007	1,269	1,564	2,004

Source: Statistics Canada, "Standard Industrial R&D Tables 1963–1983," background document no. SS1983–3, prepared in conjunction with SC Cat. No. 13–212.

The latter constitute the constant dollar R&D expenditures incurred in each year. The price index used to deflate R&D expenditures could be constructed from data on the prices of the elements comprising the R&D expenditures.

The major difficulty in computing R&D capital by either approach centres on the spillovers associated with knowledge capital accumulation. Knowledge capital for any single firm does not depend solely on its R&D investment but on the investment of other firms (which may or may not be in the same industry). The construction of an appropriate knowledge capital input index must take into consideration the interaction between individual firm R&D investment levels. The problem, of course,

is that firm interaction arising from the R&D investment spillovers can extend over many industries or countries. The analysis of production and investment decisions becomes quite complex because the technological linkages, as represented by the spillovers, must be included in the investigation.

Determining the spillovers involves significant complexities.

- Interrelated firm production and investment decisions must be integrated with R&D spillovers into a single model capable of being tested.
- The spillovers can be transmitted through complicated mechanisms whose forms have to be determined.
- Firms participating in sending and receiving R&D investment spillovers have to be identified.

A solution to the problem of firm identification would be to focus on firms operating in the same industry, because they produce related products with similar technologies. Clearly, the R&D investments of these firms are mutually useful and can spill over. Estimates of these spillovers provide intra-industry externality links. Bernstein and Nadiri (1985) have begun to investigate intra-industry spillovers. Preliminary results show that about 25 percent of R&D investment spills over between firms in the U.S. chemical industry.

A difficulty even with focussing on intra-industry spillovers is that they can extend internationally. For example, firms operating in the telecommunications manufacturing industry in Canada and the United States may exhibit strong transnational technological links and thereby borrow heavily from each other. In this instance, firms operating in the same industries but in different countries would have to be analyzed within the same model.

Once we move to the nature and extent of the inter-industry spillovers, there are potentially many firms which would be involved in the technological links. In this context, Mansfield et al. (1977) avoid the problem of firm identification by focussing on the major R&D investment projects in the United States. They find that 70 percent of the investment spills over. Because only the most significant R&D investment projects are included in the sample, the magnitude of the externality may be high. Nevertheless, the findings do suggest that inter-industry links exist.

A number of alternative data sources may help in limiting a priori the number of firms involved in the inter-industry R&D investment externalities. For example, Raines (1968) uses the horizontal product field classification of the National Science Foundation to include inputs to an industry's R&D investment and also the R&D expenditures of other industries in the same product field. In addition, grouping firms by their Standard Industrial Classification categories, employing firm industrial diversification data from the Census of Manufactures and using the cross referencing of patents across product fields, could be means of limiting the sample of firms.[7]

Measurement of Inventive and Innovative Output

Output relating to product and process development activities is usually designated as invention and innovation. Their measurement is frequently deemed to be fraught with even more difficulties than the outputs emanating from activities not involving product and process development. This view is based on two arguments — the non-quantifiable nature of ideas, and the pervasiveness of random elements in the production process.

It is difficult to accept the notion that ideas are not measurable. Patenting inventions and publishing scientific information impose the condition that the idea be represented in an accessible form. Schmookler (1966) and others have argued that the number of patents is a better measure of inventive output than an index of "major inventions." He maintains that the notion of importance with respect to an invention is not as discrete as some would believe. In addition, few important inventions are not patented, and patent applications are not necessarily requested for minor ones. This implies that patents cover a large proportion of the output set of product and process developments.

A Canadian patent document includes the following information:

- application number and date;
- issue number and date;
- patent classes;
- title of invention;
- name and country of residence of the inventor;
- name and country of residence of the patentee;
- priority date, country and application number;
- description of the invention; and
- specific claims for the invention.

We can observe that the holder of a patent is required to disclose a description of the invention, including the nature of its operation as well as its uses; thus ambiguity can be avoided. In Canada, information on the patent becomes available to the public when the patent is granted.

In 1981, some 1,437 patents were granted to 935 applicants for Canadian inventions. However, this represents only approximately 10 percent of the total number of patents granted in Canada, which means that a large number of patents were granted for foreign inventions.[8] Among the number of patents for Canadian inventions, roughly 33 percent were undertaken by 8 percent of the applicants. Table 1-6 presents the number of patentees, patents, and the major corporate patentees.

The second measurement impediment centres on the degree of uncertainty in the production of inventive output and innovation. Clearly, all production processes involve random elements. Agriculture requires the combined inputs of seeds, fertilizer, land, labour, and equipment to

TABLE 1-6 Patent Concentration in Canada, 1981

Number of Patentees	Number of Patents
1	More than 50
2	20–50
10	10–19
17	5–9
135	2–4
770	1
Total 935	1,437

Major Corporate Patentees	Industry
Northern Telecom	Electronics, Electrical Products
Canadian General Electric	Electronics, Electrical Products
Imperial Oil	Oil Extraction and Refining
Polysar	Chemicals and Rubber
Sherritt Gordon Mines	Mining and Smelting
Inco Ltd.	Mining and Smelting
Alcan	Alum. Smelting and Fabrication
Cominco	Mining and Smelting
Du Pont Canada	Chemicals and Rubber
General Foods Ltd.	Food and Beverages
Westinghouse Canada	Electronics, Electrical Products
Gulf Oil	Oil Extraction and Refining
Domtar	Pulp and Paper, Chemicals
Dominion Engineering	Heavy Machinery
Dow Chemical of Canada	Chemicals and Rubber
Uniroyal Ltd.	Chemicals and Rubber
Mitel	Electronics and Electrical Products

Source: Derived from Canada, Department of Consumer and Corporate Affairs, PATDAT, Ottawa, 1981.

produce various crops. Variations in output can occur for non-input-related reasons such as weather changes. Examples also occur in manufacturing industries, where labour strikes, government-imposed embargos, and war can affect the flow of output. The argument relating to product and process development presupposes that the stochastic or random influences are not just present but also continuously outweigh any recurrent factors. The dominance of accidental influences implies that any formula used to measure inventive output or innovation must be misleading. From case studies of individual projects (see Mansfield et al. 1971) to econometric analyses of aggregate production structures (see Hausman, Hall, and Griliches, 1984), a relatively stable relationship has been established between inputs and outputs pertaining to product and process development. Indeed, the existence of facilities, financing, and government policy devoted to producing inventions and innovations is evidence that an input-output relationship exists.

Inventive output is generally measured by the number of patents, but patents do not fully reflect all inventions. The reason is that the inventor, in order to establish property rights, can either not disclose the invention or take out a patent. The latter option involves the disclosure of the invention. The selection that emerges for any invention depends on the net benefits of secrecy versus the net benefits of patenting.

The characteristics of the invention may lend itself to secrecy. For example, certain products are not prey to copying. Specific cases would be Smith's Black Cough Drops, the Coca Cola syrup recipe, and the Zildjian percussion cymbals, all of which have been family secrets for generations. Hence, firms are apt to select the secrecy route when it is quite costly to copy the invention through the product itself. It is not only complex physical processes that lend themselves to secrecy, but also specialized human skills, such as gourmet recipes. In these cases, the cost of imitation may be excessive.

Notice that there are two types of production available to any invention — secrecy or self-protection, and patent protection. The benefit of keeping an invention secret is that other economic agents cannot imitate it. However, there are also costs. Secrecy generates a weakly defined property right because the owner of the knowledge cannot exclude others from discovering the invention independently. Thus, there are significant monitoring costs which must be undertaken in order to protect the secret. Second, there is the cost to the firm of not inventing because the potential inventor feels that the cost of successfully copying may be lower than the cost of the original effort of inventing.

Clearly, costs are incurred to protect the secret from disclosure. In contrast, it is precisely disclosure that patent protection offers. The costs of self-protection — or in other words, the costs of disclosure — are precisely the benefits of patent protection. The patent prohibits copying and so monitoring costs are not as great, although a certain amount of policing is always necessary in order to detect patent infringement.

To protect an invention through a patent, the firm must articulate the knowledge. This procedure delineates the right of the inventor. The process is difficult, and it is precisely in this situation that the costs of patent protection arise. A famous example of the costs of disclosure is the patent on J.W. Paige's typesetting machine. The first application contained 204 sheets of drawings with 1,000 views. Later applications added 275 figures and 613 claims. The more difficult the task of adequately characterizing the invention, the higher the costs of patenting, because imitation is facilitated. In general, the lower the costs associated with patenting, the more accurate patent numbers are as indicators of inventive output. Thus, fewer inventors will self-protect.

Innovative output relates to changes in the characteristics of existing products and production processes. Measuring innovative output

depends on a link between the product or process and its component characteristics. For example, the R-factor in insulating material or the computing ability of microprocessors may represent a means of measuring innovations associated with these products. Unfortunately, data on innovative changes are readily available on an ongoing basis for only a few industries. Among the major industries where adjustments are made to the base quantity (or volume) data are automobiles and housing. Clearly, much more work is needed in this area both in terms of methodology and data construction.

R&D, Patents and Empirical Evidence

It is a generally established empirical result that R&D investment has a significant and positive influence on productivity growth and thereby also on the growth of output. Moreover, patents have been found to be an important indicator of technological change. The purpose of this section is to discuss and survey the empirical results pertaining to the relationships between R&D capital, patent frequency, productivity growth, output, and prices.

R&D, Productivity Growth and Output

The majority of work on R&D investment and production has focussed on the output expansion effects. In particular, much effort has gone into exploring the relationship between R&D capital accumulation and total factor productivity (TFP) growth. The reason is quite simple: TFP growth is a function of the rate of technological change. Since R&D investment is a source of this change, it is quite natural to investigate the impact of R&D investment on TFP growth.

Mansfield (1965, 1968, ch. 4) finds that the rate of technological change or TFP growth for ten U.S. manufacturers is directly related to the growth rate of R&D capital. This result is true regardless of whether technological change is disembodied or capital-embodied. He also obtains similar results for ten chemical and petroleum firms. In accounting for TFP growth, Mansfield estimates that 20 percent of the result arises from the growth in R&D capital when technical change is disembodied. When it is capital-embodied, then the growth in R&D capital causes about 70 percent of TFP growth.

Investigating U.S. agriculture, Griliches (1964) finds that the growth rate of knowledge capital accounts for almost 30 percent of TFP growth. Griliches (1973) also estimates the relationship for U.S. manufacturing among samples of industries classified according to Standard Industrial classification categories at the 2-, 3- and 4- digit level, where 40 percent of TFP growth is accounted for by R&D growth.

Terleckyj (1974, 1980) identifies two kinds of effects on TFP growth. He defines direct effects as those which emanate from the R&D investment conducted in the industry under consideration, and indirect effects as those which arise from the purchases of intermediate and physical capital inputs. Dealing with 20 U.S. manufacturing industries, he estimates that 30 percent of TFP growth is accounted for directly by the accumulation of privately financed R&D capital. He finds no direct effect associated with government-financed R&D capital. The indirect effect obtained for privately financed R&D capital accumulation amounts to 78 percent of TFP growth.[9] Once more, there is no indirect effect associated with government-financed R&D capital.[10]

Mansfield (1980) investigates the contribution of R&D capital to TFP growth by distinguishing between basic and applied R&D investment. He finds for U.S. manufacturing industries and for U.S. petroleum and chemical firms that the growth rate of basic R&D capital has a positive and significant influence on TFP growth. He divides applied research at the industry level into private and public sector financing components, and this split does not influence the results, although it appears that the sectoral financing composition affects basic R&D capital. In addition, there is a significant influence of the indirect effect through R&D capital embodied in an industry's purchased inputs. Once more, only the private sector financing amount of R&D capital matters.

Scherer (1982) finds that both the direct and indirect effects of R&D capital during the 1945–65 period exerted a significant effect on TFP growth for U.S. manufacturing industries. However, this relationship seems to have weakened during the 1970s. Scherer emphasizes inter-industry dependence, and finds that the role of R&D capital to the industry of use (the indirect effect) is more powerful than the link between R&D capital and industry of origin (the direct effect).

Nadiri and Schankerman (1981) decompose TFP growth into a factor price effect, a product demand effect, an R&D effect, and an autonomous technical change effect. The decomposition is carried out for U.S. total manufacturing, durables, and non-durables over the periods 1958–65 to 1965–73 and 1965–73 to 1973–78. Generally, the product demand effects dominated in the latter period for manufacturing and durables, accounting for about 65 percent of TFP growth. In the earlier period for these two groups, technical change was the major determinant, accounting for about 75 percent. The results were slightly different for non-durables. In the earlier period about 45 percent of TFP growth was explained by technical change, and in the later period 45 percent was determined by product demand, while 55 percent was accounted for by the factor price effect. The impact from R&D capital increased in the later period for all three categories. It accounted for the smallest proportion of TFP growth for manufacturing and non-durables, while for durables R&D capital growth ranked in the middle. Defining the sum of the factor price and

product demand influences to be the scale effect and the sum of the R&D and exogenous technical change determinants to be the technology effect, in all three categories, the technology effect dominated in the early period and the scale effect in the later years.

In Canada, Lithwick (1969) reports that he is unable to find a link between the R&D capital and TFP growth rates. Most recently, Switzer (1984), using the approach of Mansfield, Griliches, and Terleckyj and developing a sample of 14 industries, finds that 60 percent of TFP growth is accounted for by the growth in R&D capital. In addition, he estimates that only privately financed R&D capital significantly affects TFP growth. Although the Switzer results are similar (but higher) to those found for U.S. studies, they should be considered with care for a number of reasons. First, they present conflicting evidence concerning the inclusion of intermediate inputs in the production process. Switzer does not attempt to test whether value-added or total output (output inclusive of the intermediate inputs) is the appropriate output measure, in spite of the fact that the measures of TFP growth are quite sensitive to the introduction of intermediate inputs into the analysis. Moreover, the statistical significance relating to R&D capital accumulation is dependent on the inclusion of intermediate inputs. Second, profit-maximizing conditions are employed for the capital-labour ratio, but not for R&D capital. There appears to be an assymmetric treatment of the factors of production, even though, as Mansfield (1968, p. 4) states, "Econometric studies . . . indicate that the total amount a firm spends on research and development is influenced by the expected profitability of the R&D projects under consideration . . ." Nevertheless, the Switzer paper does provide some evidence of a link between the growth rates of TFP and R&D capital.

Griliches (1980) estimates the effects of R&D capital accumulation on the labour productivity growth rate for six U.S. industries. He finds that about 30 percent of labour productivity growth is determined by the accumulation of R&D capital. Nadiri (1980) obtains a figure of 35 percent for the private sector of the U.S. economy. Scherer (1982), in dealing with U.S. manufacturing, divides the effects on labour productivity growth into direct and indirect. He estimates that the indirect effects were larger than the direct influences during the 1945–65 period, but that both determinants diminished in strength during the 1970s.

In Canada, Longo (1984), dealing with a cross-section of firms, finds that 64 percent of labour productivity in the chemical industry is explained by R&D capital accumulation, compared with 16 percent in the electrical industry. For all other industries, there is no significant relationship. However, on average (over all the firms), the growth in R&D capital accounts for about 60 percent of labour productivity growth. Longo's measure of the R&D capital stock is $1,347 million in 1980 (p. 48). This measure is based on accumulated R&D expenditures from 1972 to

1979, using a depreciation rate of 12.5 percent. His sample includes about 70 percent of manufacturing R&D expenditures, which amounted to $1,213 million in 1980 (see Table 1-5). The R&D expenditures relating to Longo's sample can therefore be calculated at $849 million for 1980. This means that the R&D expenditures in a single year are 63 percent of the eight-year accumulation of these expenditures. From other studies (for example, Nadiri and Bitros, 1980), the stock of R&D capital appears to be too small. Indeed, knowledge capital seems to be anywhere from one-sixth to one-half of the stock of physical capital. Longo's measure of physical capital amounts to $34,670 million for 1980. Taking only one-sixth of this figure gives an estimate for R&D capital of $5,778 million for 1980. With this figure, the growth in R&D capital thus accounts for about 13.5 percent of labour productivity growth. This percentage is almost equal to the 11 percent figure which Longo estimates to be the contribution of physical capital accumulation to labour productivity growth (p. 39). The equality of the contribution to labour productivity growth by both types of capital brings into question Longo's conclusion (p. 3) that the rate of return on R&D investment exceeds that for other investments, and his policy prescription that R&D investment should be increased by two-thirds over 1979 levels.[11]

Postner and Wesa (1983) also investigate the relationship between the growth rates of labour productivity and R&D capital accumulation in Canada. They find that there is no significant relationship between the two growth rates. However, when they take into consideration the inter-industry effects, the indirect influences are found to have a significant impact on the labour productivity growth rate. In particular, Postner and Wesa find a positive effect associated with indirect intramural R&D investment and a negative effect for indirect extramural R&D capital accumulation.[12] As Postner and Wesa state with respect to the negative effect: "The precise explanation for this (perverse) result is a mystery at present . . . . Further investigation of this matter is clearly called for" (p 33). The difficulty with this result, of course, is that the marginal contribution to output of indirect extramural R&D capital is negative. Using a similar framework to Postner and Wesa, Hartwick and Ewan (1983) also estimate that there is no statistically significant relationship between R&D investment and labour productivity growth. Their results are independent of the inclusion of direct and indirect effects. This leads Hartwick and Ewan to reject the "downstream labour productivity growth hypothesis" associated with R&D capital accumulation.[13]

The impact of R&D capital on output has been generally consistent over the years. Mansfield (1968), Minasian (1969) and Griliches (1973) estimate that on average for U.S. manufacturing and other industries, a 1 percent increase in R&D capital leads to a 0.1 percent increase in output. In Canada, Globerman (1972) reports he is unable to find a significant

effect of R&D capital on output. More recently, Switzer (1984) states he finds results similar to those in the United States.

There is a tendency to consider the composition of productivity growth accounted for by a R&D investment as a rate of return to R&D capital. In adhering to this tendency, the empirical results show that the rate of return to R&D capital ranges from 20 to 70 percent on average in the United States and from 20 to 60 percent in Canada. The real issue, however, pertains to whether and in what sense these composition percentages can be considered as rates of return. First, most of the previous percentages measure the incremental contribution of R&D capital to output (the marginal product of R&D capital). The marginal product of knowledge capital (net of depreciation) in long-run competitive equilibrium is indeed equal to the (long-run marginal) rate of return on this form of capital. This is true as long as firms are profit-maximizers with respect to the production structure hypothesized in the estimated models. The difficulty is that the conditions associated with profit maximization are not imposed in the model. Therefore, this hypothesis (not just profit maximization, but profit maximization with respect to the postulated set of inputs and outputs and their associated streams of costs and revenues) needs to be accepted as a matter of faith.

Second, R&D capital (as mentioned) consists of scientists and engineers, laboratories, and associated equipment. These inputs may be counted in the labour and physical capital components as well. In this instance, the estimated marginal product must be considered as the excess long-run marginal rate of return on R&D capital. This point is recognized by Terleckyj (1974, 1980) and Griliches (1980). Therefore, a statistically insignificant marginal product of R&D capital does not imply that its rate of return is zero. The implication of the insignificance is that the excess rate of return (relative to, say, physical capital) is zero.[14]

There is a normative implication which is sometimes drawn from the estimation of rates of return or excess rates of return. If the rate of return on R&D capital exceeds that on physical capital (or if the excess rate of return on the former type of capital is positive), then there is a presumption that there exists an insufficient stock of knowledge in society. This argument is based on the hypothesized arbitrage condition that expected (as opposed to actual) rates of return (at the margin) on different types of capital must be equalized.[15] Hence, if (for example) the expected rate of return on R&D capital exceeds that on physical capital, then the level of R&D capital should be expanded until its expected rate of return declines to the rate on physical capital.

There are a number of difficulties with the hypothesis which attributes differences in actual rates of return to the adequacy of capital stock levels. These problems are related to the acceptability of the arbitrage condition and the identifiability of actual rates of return to expected

rates.[16] First, if individuals or groups are able to diversify their risk from undertaking investment projects, then expected rates of return will be equal. The arbitrage condition is an outcome of the diversification process. In this instance, if the measured (or actual) rates of return differ, then there is no presumption concerning the socially optimal level of capital. The fact that actual rates differ reflects the reality that individuals make mistakes; some lose and some win from the various projects.

Second, if individuals are not able to diversify away all the risks, then expected rates of return will differ. The differences in the expected rates reflect the degree to which risks must be absorbed by the investors (in knowledge capital, for example). Thus, the arbitrage condition represented by the equality of expected rates of return is not appropriate. In this case, differences in actual rates reflect differences in the riskiness of alternative investment projects. Once more, there is no presumption concerning the socially optimal level of capital.

It is sometimes argued that risks which cannot be diversified away by individuals may be diversifiable by society as a whole. Hence, from society's vantage point, expected marginal rates of return should be equalized. First, it is not clear that all risk in a society can be diversified away even by a government operating in the public interest. For example, society as a whole will be risk averse when the variance of the stream of returns from an investment project is large and not independent of other projects.[17] Indeed, this may be a reason for observing foreign investment, as individual economies cannot absorb certain risks because risk pooling over individuals or projects is not tenable. Second, governments, like private sector groups, have a comparative advantage in risk diversification for particular types of investment projects. This appears to be quite obvious because of the simultaneous provision of private and public sector insurance, for example. Thus even from society's view, expected marginal rates of return on alternative investment projects can differ.

Output and Factor Price Determinants of R&D Capital

R&D capital is a factor of production. Therefore, it is determined by factor prices, output prices, and quantities. Moreover, the demand for R&D capital is determined in conjunction with all the inputs in the production process.

Recent work in Canada and the United States has focussed on the decisions governing R&D capital requirements within the context of production analysis. Previously, R&D expenditures were related to sales, profits, industry concentration, or entry barriers. Work by Comanor (1967), Scherer (1967), Mansfield (1968), Grabowski (1968), Mansfield et al. (1971), and Howe and McFetridge (1976) estimate some interesting empirical relationships.

- Larger firms do not spend more on R&D than smaller firms, relative to their size.
- There is a positive relationship between the degree of concentration and R&D expenditures, as long as the industry is not overly concentrated.
- R&D expenditures tend to be highest in industries where entry barriers are not overly high or low.
- Growth in sales stimulates R&D expenditures.
- Profits and R&D expenditures are directly associated.

There are some difficulties in interpreting these results because of the nature of the analytical framework employed. Generally, there is only an implicit model of industry structure, and hence concepts like entry barriers are used in an ad hoc fashion. Also, R&D expenditures are assumed to be determined in isolation from other corporate decisions. This imposes a strong degree of separation with respect to firm activities. Moreover, the number and size distribution of firms in an industry are assumed to be exogenous. Yet a model of industry structure must be able to explain these two phenomena. In particular, the degree of concentration is endogenous. As Dasgupta (1982) notes, there is a positive linear relationship between concentration and the ratio of R&D to sales. However, he claims that no causality can be imputed to this relationship because both variables are simultaneously determined. Developing and estimating models of industry structure is an important avenue to understanding the determinants of R&D investment. There is a need to integrate product demand elements with firm cost characteristics and corporate rivalries. However, at the present time, there is no empirically integrated model.

Current efforts to understand R&D capital accumulation have centred on its role in affecting the production and cost structure of a firm. In this respect, output has been estimated to be an important determinant of the demand for R&D capital. Nadiri and Bitros (1980) find that in the long run, for five U.S. industries, an increase in output of 1 percent generates a 0.7 percent increase in R&D capital. These estimates are somewhat smaller for the larger firms and larger for the smaller firms. Bernstein and Nadiri (1984) estimate long-run output effects for R&D capital relating to four U.S. industries, and find that the estimates in each are slightly greater than unity and are in line with those estimated for physical capital. In Canada, Bernstein (1984a) develops a sample of major firms undertaking R&D investment, and estimates the long-run effects to be around unity. The short-run effects are found to be one-quarter of those found in the long run. In addition, when Canadian-owned firms are considered separately from the U.S. subsidiaries, Bernstein (1984b) estimates that there is no difference in the long run between the output effects. However, in the short run, when output increases by 1 percent,

the U.S. subsidiaries increase their demand for R&D capital by 0.25 percent, compared with 0.37 percent for the Canadian-owned firms. The former group of firms exhibit an impact which is two-thirds that of the latter set.

There are a number of implications of these results.

- The demand for R&D capital is directly affected by output.
- There is no evidence to suggest that output growth leads to larger than equiproportional growth in R&D capital.
- Short-run influences are smaller than long-run effects.
- U.S. subsidiaries and Canadian-owned firms exhibit the same magnitude in the long run, but in the short run Canadian-owned firms respond more to output changes.
- Output exerts a much stronger influence on R&D capital compared with the converse situation; in fact, the difference in effects may be as much as tenfold.

Factor prices also affect decisions governing the level and growth of R&D capital. Rasmussen (1973) investigates the effects of changes in the price of labour and physical capital on R&D capital. He finds that the latter is sensitive to these prices. Nadiri (1980) develops a rental rate for R&D capital related to U.S. manufacturing. He estimates that a 1 percent increase in this factor price causes a 0.6 percent decline in the demand for R&D capital. Bernstein and Nadiri (1984) find a similar result for various U.S. industries. They estimate the price response generated to be a 0.45 percent decrease in the demand for knowledge capital. Moreover, they estimate an array of long-run factor price effects. Their results illustrate that at a given level of output supply, physical and R&D capital tend to complement each other. An increase in the rental rate on physical capital causes the demand for R&D capital to decline on average by 0.2 percent. The exact magnitudes, however, vary among the industries. In addition, at a given level of output, both types of capital inputs displace labour requirements. Thus, decreases in the factor price of R&D capital cause the demands for both knowledge and physical capital to increase, while the demand for labour declines. If the rental on R&D capital decreases by 1 percent, in the long run, labour requirements fall by about 0.25 percent. Although each capital input is a substitute for labour, the empirical results point out that even in the long run, labour demand is not very responsive to changes in the factor price of R&D capital.

In the Canadian context, Bernstein (1984a) estimates a set of factor price effects in the short and long runs. These results are presented in Tables 1-7 and 1-8. In the long run, a 1 percent increase in the price of R&D capital causes demand to decrease by only about 0.35 percent. The short-run effect is about three times smaller than the long-run effect. As for the United States, in the long run, capital inputs are complements while each capital input is a substitute for labour. In addition, this

TABLE 1-7 Elasticity Coefficients of Long-Run Price Responses of Factor Demands, Major Firms in Canada

	Factor Demand[a]		
	Physical Capital	R&D Capital	Labour
Factor Price:			
Physical Capital	−.3038	−.1600	1.1702
R&D Capital	−.0480	−.3240	.4265
Labour	.3518	.4840	−1.5967

Source: J.I. Bernstein, *Research and Development, Production, Financing and Taxation* (Toronto: University of Toronto Press for the Ontario Economic Council, 1984).
a. Response to a 1 percent increase in price of the factor, when output does not change.

TABLE 1-8 Elasticity Coefficients of Short-Run Price Responses of Factor Demands, Major Firms in Canada

	Factor Demand[a]		
	Physical Capital	R&D Capital	Labour
Factor Price:			
Physical Capital	−.1230	−.0472	.6911
R&D Capital	−.0083	−.1284	.2492
Labour	.1313	.1756	−.9403

Source: J.I. Bernstein, *Research and Development, Production, Financing and Taxation* (Toronto: University of Toronto Press for the Ontario Economic Council, 1984).
a. Response to a 1 percent increase in price of the factor, when output does not change.

relationship between the factors of production is also obtained in the short run. In the long run, a decrease in the rental on R&D capital increases the demand for physical capital by 0.05 percent, and decreases the demand for labour by slightly over 0.40 percent. In the short run, the demand for capital increases by 0.01 percent, and demand for labour decreases by 0.25 percent as a result.

Bernstein (1984b) looks at the factor price effects for both Canadian-owned firms and U.S. subsidiaries. The results, given in Tables 1-9 and 1-10, point out that a 1 percent increase in the price of the R&D capital input in the long run decreases the demand by 0.42 percent for U.S. subsidiaries and by 0.28 percent for Canadian-owned firms, which is two-thirds the magnitude for the U.S. subsidiaries. In the short run, the effects are half the long-run magnitude (see Tables 1-11 and 1-12). In the long run, the qualitative relationship between the various inputs does not distinguish between the types of corporate ownership; at a given level of output, the capital inputs are complements, and each capital input is a substitute for labour. In the short run, the capital inputs are not complements. Indeed, a decrease in the factor price of R&D capital leads to a decrease in the demands for both physical capital and labour, at a given level of output (see the second row in Tables 1-11 and 1-12).

TABLE 1-9 Elasticity Coefficients of Long-Run Price Responses of Factor Demands for U.S. Subsidiaries

	Factor Demand[a]		
	Physical Capital	R&D Capital	Labour
Factor Price:			
Physical Capital	−.2622	−.0332	.7744
R&D Capital	−.0271	−.4234	.5030
Labour	.2894	.4566	−1.2775

Source: J.I. Bernstein, "Corporate Ownership, Production, Tax Policy and Research and Development," Report to the Federal Department of Regional Industrial Expansion (Ottawa, 1984).

a. Response to a 1 percent increase in price of the factor, when output does not change.

TABLE 1-10 Elasticity Coefficients of Long-Run Price Responses of Factor Demands for Canadian-Owned Firms

	Factor Demand[a]		
	Physical Capital	R&D Capital	Labour
Factor Price:			
Physical Capital	−.2802	−.0382	1.0234
R&D Capital	−.0388	−.2795	.5384
Labour	.3190	.3177	−1.5617

Source: J.I. Bernstein, "Corporate Ownership, Production, Tax Policy and Research and Development," Report to the Federal Department of Regional Industrial Expansion (Ottawa, 1984).

a. Response to a 1 percent increase in price of the factor, when output does not change.

TABLE 1-11 Elasticity Coefficients of Short-Run Price Responses of Factor Demands for U.S. Subsidiaries

	Factor Demand[a]		
	Physical Capital	R&D Capital	Labour
Factor Price:			
Physical Capital	−.1581	−.0058	.3563
R&D Capital	.0128	−.2105	.2617
Labour	.1453	.2162	−.6180

Source: J.I. Bernstein, "Corporate Ownership, Production, Tax Policy and Research and Development," Report to the Federal Department of Regional Industrial Expansion (Ottawa, 1984).

a. Response to a 1 percent increase in price of the factor, when output does not change.

TABLE 1-12 Elasticity Coefficients of Short-Run Price Responses of Factor Demands for Canadian Owned Firms

	Factor Demand[a]		
	Physical Capital	R&D Capital	Labour
Factor Price:			
Physical Capital	−.0933	−.0077	.5384
R&D Capital	.0104	−.1247	.2904
Labour	.0829	.1324	−.8287

Source: J.I. Bernstein, "Corporate Ownership, Production, Tax Policy and Research and Development," Report to the Federal Department of Regional Industrial Expansion (Ottawa, 1984).

a. Response to a 1 percent increase in price of the factor, when output does not change.

Schwartz (1983) also looks at the relationship between R&D capital and three factors of production (labour, physical capital, and energy) for 14 manufacturing industries in Canada. His approach is quite different from the treatment of R&D capital as a factor of production. In Schwartz's model, the stock of R&D capital is given to the industry (even in the long run). There is no explanation of the determinants of R&D capital. Hence labour, physical capital, nd energy requirements depend on R&D capital, output, and factor prices, but the demand for knowledge capital is independent of these elements. Nevertheless, Schwartz finds that exogenous changes in R&D capital do not use physical capital exclusively. R&D capital accumulation also requires use of labour in paper, transportation equipment, and chemicals; capital in machinery, electrical products, and petroleum and coal; and energy in paper, petroleum and coal, and chemicals.[18]

The price effects illustrate a number of conclusions.

- R&D capital is responsive to its own price and the prices of other factors of production.
- The effect generated by its own price is significantly less than unity both in the short and long runs.
- The long-run effect outweighs the short-run effect.
- At a given level of output, in the long run, physical and R&D capital complement each other but displace labour; in the short run, there is a tendency for the factors to be substitutes.
- The output impacts on R&D capital are larger than the price effects in both the short and long runs.[19]

The Determinants of Patent Frequency

Patents are a measure of inventive output and as such they are the outcome of a production process. This view has led specialists to investi-

gate relationships between patents and R&D capital. Mansfield (1968, ch. 2) finds that for the major firms in the petroleum, steel, and chemical industries in the United States a contemporaneous and positive relationship exists between inventive output and R&D investment (measured as R&D expenditures). He estimates that an additional $2 million spent on R&D results in one additional patent.

Firms generally produce many different outputs, which can be divided into inventive and non-inventive output. Given the quantity of the factors of production within the firm, there must be a trade-off between the levels of inventive and non-inventive output.[20] A negative relationship is obtained by Mansfield for the major firms in the chemical and steel industries.[21]

Recently, Pakes and Griliches (1984), dealing with firms operating in U.S. manufacturing, estimate a positive significant relationship between patents and R&D expenditures. The exact nature of the timing pattern between inventive output and knowledge capital accumulation remains inconclusive, but there is much evidence that a strong contemporaneous relationship exists (see Hausman, Hall and Griliches, 1984).

In Canada, McFetridge (1977), using the Mansfield framework, estimates a similar set of relationships. He finds a significant positive relationship between patents and R&D expenditures and a negative relationship between patents and sales for the electrical, chemical, and machinery industries. McFetridge estimates that the R&D cost of an additional patent is $541,000, $962,000, and $182,000 in the electrical, chemical, and machinery industries, respectively.

These models focus on the production or supply side of inventive output. In other words, they stress the role of technological opportunities available to the firm. These opportunities enhance the firm's profits. Schmookler (1966) notes that both technological opportunities and the demand for the inventive output may be significant determinants for patent frequency. Indeed, he stresses the latter explanation. Scherer (1982) empirically evaluates the "technological opportunity" and "demand-pull" hypotheses. The demand-pull hypothesis is based on a model with the inventive output (or patent) as an input in the purchasing (or using) firm's production process. Moreover, the using firm's demand for this input is a function of its own output.

Scherer classifies patent data for U.S. manufacturing industries according the industries of use. Using investment in physical capital stock, material purchases, and value-added as output measures of the using industries, Scherer finds a positive, significant relationship between patents by use and the user output. However, the explanatory power of the model is weak. The technological opportunity hypothesis is tested in the usual manner by relating patents of origin to the originator's sales. Scherer finds a positive significant relationship between these variables. In addition, the explanatory power is greater than for the

demand-pull hypothesis (especially when allowance is made for industry differences).[22] Indeed, there is almost a one-to-one relationship between the growth rates of patents and sales. In other words, a 1 percent increase in sales leads to a 1 percent increase in patents.

Generally, the production of inventive and non-inventive outputs and innovation are jointly related. The outputs are dependent on factors which are simultaneously used to produce more than a single product. Thus a multi-output, multi-input approach seems appropriate in a model to explain the output supply and input demand relationships. Up to this point, little work has been directed in this manner. A step toward this approach has been taken by Bernstein (1984c). In this model, firms produce inventive and non-inventive output jointly, using physical and R&D capital and labour. However, Bernstein assumes that non-inventive output is predetermined. This allows him to derive and simultaneously estimate inventive output supply and factor demand equations which are conditioned on the level of non-inventive output and factor prices. Bernstein finds for major firms producing inventive output in Canada that in the short run a 1 percent increase in non-inventive output (deflated sales) causes patents to increase by 0.64 percent, and in the long run the elasticity is unity. In this model, factor requirements are able to expand simultaneously with patent frequency as non-inventive output increases. This latter result is quite similar to that found by Scherer (1982) for the United States, using a different approach. In addition, Bernstein estimates that increases in all factor prices cause patent frequency to decline. These price effects are significant but small. Indeed, a 1 percent increase in the rental rate on R&D capital causes patents to decline by 0.05 percent. Further work is needed in this area to allow for a more complete analysis of a multi-output framework where inventive and non-inventive outputs are simultaneously determined.

Government Policy and R&D Capital Accumulation

The Canadian government has introduced a wide variety of policies over the years to stimulate the rate, direction, and diffusion of technological change in general and of R&D capital accumulation in particular. Policies have centred on providing scientific and technical information, legislation on property rights, tax incentives, and grants and loans, as well as on encouraging purchases of innovation and inventive output and public sector production of these two types of output. This section focusses on the tax and grant policies of the federal government because of their relative importance in the policy arsenal and their pervasiveness in the industrial fabric.

General Policies

Besides policies intended to influence R&D capital formation directly, there are many policies which influence output, employment, physical

investment, and interest rates, which in turn affect the level of R&D capital. The manner in which these policies cause changes in the demand for R&D capital arises through the output and factor price effects. First, policies designed to stimulate the level of product demand, whether through tax decreases or expenditure increases, exert a significant effect on R&D capital formation. These influences operate through the substantial and positive output effects associated with the demand for R&D capital.

Second, policies designed to stimulate physical capital formation and employment affect the relative prices of these factors of production. For example, accelerated depreciation of equipment and structures (not used in R&D investment) decreases the rental rate on physical capital. Two effects ensue. The substitution effect causes firms to alter the relative proportions of the inputs in the production process. Because physical and R&D capital are complements and each is a substitute for labour, the substitution effect associated with the accelerated depreciation on physical capital causes demand for R&D capital to increase and labour requirements to decrease. The output effect arises because the decrease in the rental on physical capital causes production costs to decline and therefore output expands. The increase in output triggers an increase in the demand for all inputs (although not in the same proportion). Moreover, since output effects dominate substitution effects, the net effect is to increase labour demand, while both effects operate in the same positive direction for physical and knowledge capital.

A similar analysis can be conducted with respect to stimulating employment of individuals not associated with R&D investment. For example, subsidies to train low-skilled workers decrease the effective unit cost of labour. This decrease in the effective wage rate generates substitution and output effects. According to the substitution effect, labour demand increases while the demand for both types of capital decrease. However, the output expansion that arises causes all input requirements to increase. The output effect dominates. Hence, the demands for physical and R&D capital increase, along with the increase in labour requirements.

Policies which influence interest rates operate through the factor prices of both physical and knowledge capital. The factor price relating to any form of capital consists of two components — the financing (rate of return) and the utilizing (rate of depreciation) portions. Thus policies that cause investor rates of return to increase render financing capital formation more expensive and thereby dampen the demand for R&D capital. Clearly, an increase in these rates of return raises the factor price of R&D capital, but it also increases the input price of physical capital. There is a direct effect through the factor price of R&D capital and an indirect effect through the price of physical capital. The indirect (sub-

stitution and output) effect enhances the direct influence because R&D and physical capital complement each other in the production process.

Grants

Grants have played a significant role within the federal government's set of instruments designed to foster R&D investment. The federal government maintains a number of grant programs, each of which is intended to decrease the unit cost of a specific type of R&D investment program.

The Industrial Research Assistance Program (IRAP) was established in 1968. IRAP encourages production activities based on the physical and biological sciences and engineering. Companies incorporated in Canada that undertake R&D investment and product development innovation in Canada are eligible for IRAP grants. These grants pay staff salary costs for scientists, engineers, technicians, and other staff members. The Defence Industry Productivity Program (DIPP) was established in 1968. DIPP encourages R&D investment into product and process development in the defence industries. Assistance is given in the form of grants and repayable loans on a shared-cost basis. Generally, about 50 percent of the total cost of the selected R&D investment programs is covered. The Program for Industry/Laboratory Projects (PILP) was initiated in 1975. PILP is designed to promote the transfer of results for federal laboratories in order to develop product and process innovations. Canadian companies with adequate technical and business capability are eligible for PILP grants. Funds are provided through the negotiation of license contracts or through a contribution arrangement with Canadian companies. There are other programs such as the Industrial Regional Development Programs (IRDP) which include grants for firms of specific size or for specific types of R&D investment projects such as energy projects. All the grant programs appear to have a number of common features.

- They must be applied for and approved by the federal government.
- Firms incorporated in Canada are eligible for the programs.
- The R&D investment, or more generally the product and process development, must be undertaken in Canada.
- There is an emphasis on innovations (with commercial application of product and process development).

There has been some work in Canada on the effectiveness of government grants in stimulating R&D investment. Howe and McFetridge (1976) find in the machinery and chemical industries that firms which receive grants do not change the amount of their own spending on R&D investment projects. In other words, a dollar of a grant directed towards R&D investment leads to a dollar more of R&D expenditures — no more and no less. This is true of domestically owned and foreign-owned firms in these industries.

In the electrical industry, both foreign and domestically owned firms which receive grants spend more on R&D investment than they would in the absence of these grants. Domestically owned firms increase their own spending by more than the amount of the grants. Assuming that grants cover half the cost of an R&D investment project, they have the effect of rendering profitable projects that would not otherwise receive grants for their R&D investment; thus projects which were hitherto unprofitable for the domestically owned firms become profitable. The foreign-owned firms increase their own spending by less than the amount of the grant. This implies that funds are reallocated by the foreign-owned firms from other R&D investment projects to the ones which receive grants. Longo (1984) estimates from a cross-section of firms in Canada that domestically owned firms increase their R&D spending in proportion to their grants and foreign-owned firms tend not to increase their spending upon receipt of a grant.

Although some results are available relating to R&D expenditures and government grants, much more work needs to be done in this area. First, the different types of grants have not been differentiated in the empirical results (this may have been a problem of insufficient data). Second, grants have been related to R&D expenditures rather than to the stock of knowledge. This implies that there is only a contemporaneous influence of grants upon R&D investment, which is clearly not the case. Grants affect the contemporaneous level of R&D capital through R&D investment. The higher level of knowledge capital, in turn, generates further future increases in R&D investment and the stock of knowledge. Thus, by ignoring the intertemporal influences of grants on R&D capital, the efficacy of government grant policy may be biased downward.

Third, the empirical models used to study the influence of grants have imposed the strong assumption that the determinants of the demand for R&D capital are completely independent of the determinants of physical capital and labour requirements. Other work, relating to the nature of the structure of production, has found that there are significant interrelationships between all factors of production. Grants will, in general, influence the demand for physical capital and labour, as well as the supply of output for the grant recipients. Thus, the effects on the structure of production and the level of output must be examined when considering the effectiveness of the government grant programs.

Tax Incentives

Canada has had a varied and extensive set of tax incentives directed at stimulating R&D capital formation. Over the last decade, the following provisions have been introduced:

- Current and capital R&D expenditures can be deducted in the year they were incurred or in any year thereafter.

- Current and capital R&D expenditures in the current year are eligible for a tax credit. The tax credit rate is 25 percent for companies eligible for the small business corporate income tax rate, 20 percent for corporations operating in the Gaspé area of Quebec and the Atlantic provinces, and 10 percent for all other corporations. Deductible R&D expenditures are reduced by the amount of the credit. This credit is deductible in full against the first $15,000 of federal tax otherwise payable and in an amount up to 50 percent of the remaining federal tax otherwise payable. Unused credits can be carried forward for up to five years.
- Current and capital R&D expenditures in the current year in excess of the average of the three preceding years are eligible for a 50 percent tax allowance. Deductible R&D expenditures are reduced by the amount of the allowance.

Since the federal budget proposals of 1983, a number of changes have been introduced to the tax policies (see Canada, Department of Finance, 1983). First, the tax allowance based on incremental R&D expenditures has been eliminated. Second, with respect to the tax credit, the rates have been increased to 35 percent for companies eligible for the small business corporate income tax rate, 30 percent for companies operating in the Gaspé and the Atlantic provinces, and 20 percent for all other companies. In addition, the limitation on the extent to which the tax credit may be applied against federal taxes payable is to be removed, a three-year carry-back period has been introduced and the carry-forward period is to be increased to seven years.

There is also a further provision in the budget. Under present tax policies, the R&D investment tax credit does not provide an incentive to undertake knowledge investment if the firm has no tax liability against which it can be applied in the current year or the five-year carry-forward period. A temporary measure has been proposed to alleviate this situation. The measure provides for a refund of a portion of the R&D investment tax credits earned between April 19, 1983, and April 30, 1986. The refund, for unincorporated businesses and businesses eligible for the small business corporate income tax rate, is equal to 40 percent of the value of credits, which cannot be used to offset taxes in the year they are earned. For other corporations, the refund is equal to 20 percent.[23]

Recent empirical work estimates the effects that changes in the R&D investment tax credit and incremental allowance rates exert on the structure of production (see Bernstein, 1984a, 1984b). First, although the statutory tax credit in Canada compares favourably with that in other countries (see McFetridge and Warda, 1983), the effective tax credit is only slightly above half of the statutory rate for the major R&D investors in Canada (see Bernstein, 1984a). This implies that the problem of unutilized tax credits is particularly acute. Policy changes eliminating

the upper limit on the amount of the credit that can be claimed in any year against the tax liability, introducing carry-back provisions, and lengthening carry-forward provisions are steps in the right direction.

It is of little value to increase the statutory rate when constraints hinder firms from taking advantage of existing credits. Table 1-13 shows, under different hypotheses or assumptions of market demand for a firm's products, that a doubling of the effective tax credit rate generates a 3 to 6 percent increase in the long-run demand for R&D capital for both U.S. subsidiaries and Canadian-owned firms. In the short run, the effect is about 1.4 percent. These results encompass both the substitution and output effects associated with changes in the effective tax credit rate. The 1.4 percent increase in the demand for the R&D capital input generated about $136 million in additional industrial R&D expenditures in 1984.[24]

The increase in R&D expenditures arises from two effects. The first occurs because at a given level of output the relative factor price of R&D capital declines. The second occurs because unit production costs decline and so output increases. The 1.4 percent short-run increase in the demand for R&D capital can be broken into a substitution effect of 1.1 percent and an output effect of 0.3 percent (see Bernstein, 1984b, ch. 7 and 8).[25] Thus, the $136 million increase in R&D expenditures consists of $107 million from the substitution effect and $29 million from the output effect.

The federal government has also increased the statutory R&D tax credit rate. For firms with sales greater than $50 million, this amounts to a doubling of the statutory rate. As can be observed from Table 1-13, this implies that the long-run demand for R&D capital increased from 7 to 15 percent for both U.S. subsidiaries and Canadian-owned firms. In the short run, there was a 2.8 percent increase in the demand for R&D capital or a $266 million increase in R&D expenditures in 1984. This increase consisted of a 2.2 percent substitution effect and a 0.8 percent output effect. Hence the $266 million increase in 1984 R&D expenditures can be divided into $209 million from the substitution effect and $57 million from the output effect.

The final federal government tax policy pertains to the elimination of the R&D incremental investment tax allowance. Table 1-14 shows that eliminating the allowance causes the long-run demand for R&D capital to fall by about 4 to 7 percent, while in the short run the demand decreases by around 1.1 percent. Thus, R&D expenditures declined by about $104 million in 1984 because of the elimination of the tax allowance on incremental R&D investment. This $104 million decrease is composed of a $82 million substitution effect (or 0.8 percent) and a $22 million output effect (or 0.3 percent). The net effect on R&D expenditures was to increase the 1984 value by $298 million. This increase consists of $234 million due to the substitution effect and $64 million due to the output effect.

TABLE 1-13 Effect on Demand for R&D Capital from an Increase in the R&D Investment Tax Credit

	Price Elasticity of Demand for a Firm's Products[a]		
	−6	−3	−1.5
U.S. subsidiaries:			
Effective tax credit			
Long run	.058	.042	.034
Short run	.016	.015	.014
Statutory tax credit			
Long run	.137	.098	.079
Short run	.013	.032	.031
Canadian-owned firms:			
Effective tax credit			
Long run	.059	.038	.027
Short run	.013	.010	.009
Statutory tax credit			
Long run	.152	.096	.068
Short run	.033	.026	.022

Source: J.I. Bernstein, "Corporate Ownership, Production, Tax Policy and Research and Development," Report to the Federal Department of Regional Industrial Expansion (Ottawa, 1984).

a. Response to a 1 percent increase in effective and statutory tax credit rates.

TABLE 1-14 Effect on Demand for R&D Capital from a Decrease in the R&D Incremental Investment Tax Credit

	Price Elasticity of Demand for a Firm's Products[a]		
	−6	−3	−1.5
	−0.06	−0.03	−0.015
U.S. subsidiaries:			
Long run	−.069	−.050	−.040
Short run	−.018	−.017	−.016
Canadian-owned firms:			
Long run	−.075	−.048	−.034
Short run	−.017	−.013	−.011

Source: J.I. Bernstein, "Corporate Ownership, Production, Tax Policy and Research and Development," Report to the Federal Department of Regional Industrial Expansion (Ottawa, 1984).

a. Response to a 1 percent decrease in the incremental investment tax rate.

The tax policy changes result in a decrease in the tax liability of the private sector (see Table 1-15). The cost to the federal government of solving the problem regarding tax credit utilization (that is, increasing the effective rate up to the statutory rate) was $125 million in 1984.[26] The cost of doubling the statutory R&D tax credit was about $251 million in 1984, while the cost decrease due to the elimination of the allowance was

TABLE 1-15 Additional R&D Expenditures and Decrease in Tax Revenues Resulting from R&D Tax Policy Changes, 1984

	Additional R&D Expenditures ($Millions 1984)			
	Substitution Effect	Output Effect	Total Effect	Decrease in Tax Revenues
		($millions)		
Tax policy:				
Increasing tax credit utilization	107	29	136	125
Doubling tax credit rate	209	57	266	251
Abolishing tax allowance	−82	−22	−104	−100
Net impact	234	64	298	276

Source: J. I. Bernstein, *Research and Development, Production Financing and Taxation* (Toronto: University of Toronto Press for the Ontario Economic Council, 1984).

$100 million in 1984. Therefore, the net cost to the government was $276 million. Notice that the additional R&D expenditures exceed the cost of the policy change when both substitution and output effects are accounted for, but the cost exceeds the increase in R&D expenditures arising from the substitution effect alone.

Conclusions

The paper has analyzed the consequences and determinants of product and process development as well as the effectiveness of government grants and tax incentives on the rate of R&D investment. Product and process development has been characterized as a production process whose inputs and outputs are jointly determined within the general set of corporate production activities.

Most of the empirical work has addressed the output expansion and factor substitution possibilities associated with R&D investment. Indeed, Canadian evidence has established that there is some influence of the accumulation of knowledge capital on productivity growth. This evidence is weaker and not as prevalent as that found for the U.S. economy. Nevertheless, R&D investment in Canada accounts for some 20 to 60 percent of the proportion of productivity growth experienced.

The demand for R&D capital responds significantly to both output expansion and factor price changes. With respect to the former effect, the demand for R&D capital in the long run increases in proportion to output increases. The influence in the short run is about a quarter of that

found in the long run. These results are similar to those estimated for firms operating in the United States. In addition, Canadian-owned firms and U.S. subsidiaries appear to respond to output changes in the same fashion in the long run, although Canadian-owned firms are more responsive in the short run. The implication from these results is that the rate of output growth plays an important role in determining the rate at which corporations devote resources to R&D investment. In fact, although R&D investment influences output growth, the converse effect is as much as ten times larger.

The influence of factor prices on the demand for R&D capital points out that there is an interaction with physical capital and labour requirements in the production process. The factors of production tend to be substitutes in the short run but physical and knowledge capital complement each other in the long run, while each type of capital is a substitute for labour. This result occurs whether the firm is a U.S. subsidiary or is Canadian-owned. However, all factor price influences are significantly smaller than the output expansion effects. Indeed, the demand for R&D capital is three times more responsive to changes in output, compared with changes in its factor price. This implies that in a growing economy, all input (labour, physical, and R&D capital) requirements will increase even if relative factor prices are changing. The output expansion effect dominates the factor substitution effect. However, in an economy with little or no growth and a rising relative price for labour, firms' production processes will become more capital intensive in terms of both physical and R&D capital. Since R&D capital consists of scientists, engineers, and technicians, firms substitute equipment, structures, and skilled labour for unskilled labour.

Grants and tax incentives exert an influence on the demand for R&D capital and the rate of R&D investment. Grants have not been studied to the same degree as the tax incentives, but there is evidence that firms which are grant recipients increase their own spending on R&D investment. Domestically-owned firms seem to be more responsive to grants than foreign-owned firms operating in Canada. However, it is still an open issue (and worthy of further work) whether firms increase their own spending on R&D investment projects less than, more than, or equal to the additional funds emanating from a government grant.

Tax incentives generate positive effects on R&D expenditures. A severe problem has been the inability of firms to utilize all of their tax credits. The effective tax credit rate is about half the statutory rate. The solution to this problem generates about one dollar in R&D expenditures for every one dollar lost in tax revenues. Once the credit utilization issue has been dealt with, a policy of increasing the statutory credit rate would generate one dollar of additional R&D expenditures for every dollar lost in tax revenues. Simultaneously, however, the recent elimination of the R&D incremental investment tax allowance causes R&D expenditures to

decrease by about one dollar for every dollar increase in tax revenues. Therefore, on net, the tax incentives generate about one dollar of additional R&D expenditures for every dollar decrease in tax revenues. Incorporated into these figures are the effects arising from changes in the structure of production (that is, the intensities by which firms utilize factors of production) and the level of output. If output expansion does not materialize, then the tax incentives generate about eighty-five cents in additional R&D expenditures for every dollar decrease in tax revenues.

There are a number of general lessons obtained from this report. First, R&D investment exerts a positive influence on productivity growth. This influence seems to vary over time and between industries. This means that "supply" elements, as represented by product and process development, affect productivity growth. In addition, industry differences must be accounted for in determining the causes of productivity growth.

Second, R&D investment responds to market forces. The rate of output supply and the array of factor prices have significant influences on the demand for R&D capital. Like other factors of production and rates of investment, R&D capital responds to the pull of the market. Output growth generates a greater demand for R&D capital. Moreover, changing factor prices (such as wage and rental rates) cause the demand for R&D capital to be altered in light of the degree by which this input is a substitute or complement for the other factors of production.

Third, policy initiatives toward R&D investment through grants and tax incentives generally lead to a dollar-for-dollar increase in R&D expenditures. A dollar spent by the government in the form of a grant or tax expenditure causes the producing unit to increase R&D expenditures by one dollar. Grants and tax incentives appear to have about the same effect on total R&D expenditures. An equal dollar value of grants and tax expenditures generates an equal amount of R&D expenditures. This implies that the greater administrative cost associated with grants is only offset by the benefit of allowing the government to target its R&D enhancement policy.

Finally, when output grows at the same rate that a grant or tax expenditure decreases the unit cost of R&D capital, R&D expenditures increase relatively more through output growth. Thus, in an expanding economy, existing policies serve to enhance the increase in R&D expenditures. However, in a contracting economy, grant and tax incentives are not able to offset the decline in R&D expenditures.

Notes

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1. See Fisher and Temin (1973) for a specification of a technology involving multiple outputs and inputs with some of each devoted in part to the production of new products and processes.
2. The jointness referred to here is not between new products and processes and existing products, but rather within the context of product and process development activities. In addition, as Dasgupta (1982) and Spence (1984) note on theoretical grounds, there is no significance to the product and process distinction. The distinction may be arbitrary to a certain extent. The more important output classification is between invention and innovations.
3. In the literature, this is also referred to as the free-rider or exclusion problem. See Reinganum (1981) and Spence (1984) for a theoretical treatment relevant to product and process development.
4. The use of input-output tables will not provide information on the extent of the spillovers between industries, unless the spillovers are linked to input purchases.
5. The purpose of this paper is not to address the multifaceted problem of technological diffusion. The issue is introduced because its importance is linked to the appropriability difficulties associated with R&D capital accumulation, invention, and innovation.
6. Statistics Canada, "Standard Industrial R&D Tables 1963–1983," background document no. SS-1983–3 prepared in conjunction with SE cat. no. 13–212, page 25 can be referred to for the breakdown between current and capital expenditures. In accounting for R&D expenditures, current and capital classifications are used. However, in developing a stock of knowledge, it seems appropriate to capitalize all expenditures pertaining to R&D. This point is brought up again at the end of this subsection.
7. Unlike other inputs for a producing unit, the R&D capital input index involves aggregation over commodities and aggregation over firms. The latter aggregation relates to the nature of the spillovers associated with R&D investment. See Diewert (1980) for a thorough discussion of aggregation over commodities and firms in the absence of spillovers.
8. This fact appears to substantiate the point that international spillovers associated with R&D investment, invention, and innovation may be quite important for Canada.
9. The direct and indirect effect accounts for more than 100 percent of TFP growth because certain other effects (such as the degree of labour unionization) exert a negative influence.
10. The reason that the source of financing R&D capital accumulation could affect the growth in TFP is not addressed.
11. There are some technical problems with the Longo (1984) study. One difficulty is that he uses output as a dependent variable and utilization (defined as output over capacity) as an independent variable. Since output is a stochastic variable in the estimation, the model contains stochastic regressors and the ordinary least squares procedure is inappropriate. Indeed, one must isolate output as the dependent variable in the model. It is not, as Longo claims, that: "In either case, the structural parameter estimates would be identical" (p. 38).
12. Intramural R&D capital of a firm relates to the quantity "constructed" by that firm, while extramural R&D capital relates to the quantity "purchased" from another producing entity.
13. Postner and Wesa (1983) used R&D capital growth rates in their analysis, and Hartwick and Ewan (1983) used R&D expenditures per unit of sales or the R&D intensity of sales.
14. In some work, it is not clear whether rates of return or excess rates of return are being estimated. This poses a problem especially when attempting to draw policy conclusions on the adequacy of the level of R&D capital.

15. This abstracts from spillovers, and so the rates of return are private. The focus here is on risk.
16. It is important to note that in most models used to estimate rates of return on knowledge capital, there are no relationships incorporating the equality condition between expected rates of return on different types of capital. Indeed, the equality condition does not appear either as a maintained or testable hypothesis. Based on these models, as a consequence, the equality between expected rates of return cannot be accepted or rejected, and implications from the maintenance of the hypothesis cannot be tested.
17. See Leland (1974).
18. The labour-using nature of R&D capital accumulation in transportation equipment and chemicals seems somewhat counterintuitive, especially in light of the fact that Schwartz finds output changes to be labour-saving in both industries. The maintained hypothesis of the separation of the demand for R&D capital from the other factors must be questioned, because of the positive relationship between output and R&D capital requirements and the array of factor price influences found in other studies.
19. The fact that the output effect dominates the factor price (or the substitution) effect will be important in understanding the magnitude of the influence of tax policy on the demand for R&D capital and the structure of production.
20. Care must be taken in interpreting the relationship between inventive and non-inventive output from models which do not hold all factors of production fixed. In this case, if some inputs increase then it is possible for both inventive and non-inventive output to rise. For example, estimating patents as a function of sales does not explicitly constrain all inputs to be fixed. Thus, a positive or negative relationship may be the outcome.
21. If inventive and non-inventive output production are completely independent, then there would not be any relationship between patents and sales. Mansfield obtains this result for the petroleum industry.
22. To understand the positive relationship between inventive and non-inventive output, see note 20.
23. The federal government has also introduced the scientific research tax credit (SRTC) financing mechanism. The SRTC provides for a tax credit equal to 50 percent of the amount of share or bond instruments issued to finance the R&D investment. The SRTC is intended to replace the R&D limited partnerships and the scientific research investment contract (SRIC). These latter instruments have the stipulation that the investor obtaining the use of the R&D investment tax credits also own the R&D investment. The SRTC mechanism does not contain this provision.
24. In the sample upon which the R&D expenditure figure is based, the total R&D capital net of depreciation in 1972 dollars is $1,863 million. Using the average inflation rate of the physical investment deflator, 0.0834, over the period 1972 to 1983, the R&D capital in 1984 dollars is estimated to be $4,843.8 millions. In addition, the sample of firms accounted for 50 percent of total industrial R&D expenditures. Thus $4,834.8 million x 2 = $9,687.6 million, which is the industrial R&D capital for Canada in 1984 dollars. Now .014 x $9,687.6 million = $135.6 million, which is the additional R&D expenditures in 1984 dollars brought about by a doubling of the effective R&D tax credit rate.
25. In the long run the proportion of the total effect consisting of substitution effect declines to slightly more than 50 percent. This is due to the strong effect that output exerts on the R&D capital input in the long run. See Bernstein (1984b, ch. 7 and 8).
26. The decrease in costs from the doubling of the effective tax credit rate is $24.039 million in 1972 from the sample of firms in Bernstein (1984a, chap. 7). In 1984 dollars, the figure is $62.5 million and since the sample of firms consists of 50 percent of industrial R&D expenditures, the total costs is $125 million.

Bibliography

Allen, J.A. 1967. *Studies in Innovation in the Steel and Chemical Industries*. Manchester: Manchester University Press.

Bernstein, J.I. 1984a. *Research and Development, Production, Financing and Taxation*. Toronto: University of Toronto Press for the Ontario Economic Council.

______. 1984b. "Corporate Ownership, Production, Tax Policy and Research and Development." Report to the Department of Regional Industrial Expansion, Ottawa.

______. 1984c. "Patents, Production and Tax Incentives." Report to the Federal Department of Consumer and Corporate Affairs, Ottawa.

Bernstein, J.I., and M.I. Nadiri. 1984. "Rates of Return, Research and Development and the Structure of Production: Cross Section and Time Series Evidence." In *Temporary Equilibrium and Costs of Adjustment*, edited by E.R. Berndt and M.I. Nadiri. Forthcoming. Cambridge: Cambridge University Press.

______. 1985. "Research and Development, Adjustment Costs and Spillovers: An Application of Dynamic Duality at the Firm Level." Paper presented at the NBER Summer Institute, Cambridge, Mass.

Canada. Department of Finance. 1983. "Research and Development Tax Policies." Ottawa: The Department.

Collins, E. 1982. *Tax Policy and Investment in Innovation: A Colloquium*. Washington, D.C.: National Science Foundation.

Comanor, W.S. 1967. "Market Structure, Product Differentiation and Industrial Research." *Quarterly Journal of Economics* 81: 639–57.

Comanor, W.S., and F.M. Scherer. 1969. "Patent Statistics as a Measure of Technical Change." *Journal of Political Economy* 77: 392–98.

Daly, D.J. 1979. "Canada's Comparative Advantage." Discussion Paper 135. Ottawa: Economic Council of Canada.

Dasgupta, P. 1982. "The Theory of Technological Competition." Mimeo.

Denison, E.F. 1967. *Why Growth Rates Differ: Postwar Experience in Nine Western Countries*. Washington, D.C.: Brookings Institution.

Dennis, W. 1976. "Age and Productivity among Scientists." *Science* 123, p. 724.

Diewert, W.E. 1980. "Aggregation Problems in the Measurement of Capital." In *The Measurement of Capital*, edited by D. Usher. Chicago: National Bureau of Economic Research.

Fisher, F.M., and P. Temin. 1973. "Returns to Scale in Research and Development: What Does the Schumpeterian Hypothesis Imply?" *Journal of Political Economy* 81 (1): 56–70.

______. 1979. The Schumpeterian Hypothesis: Reply. *Journal of Political Economy* 87 (2): 386–89.

Globerman, S. 1972. "The Empirical Relationship between R&D and Industrial Growth in Canada." *Applied Economics* 4: 181–95.

Goldberg, L. 1979. *The Influence of Federal R&D Funding on the Demand for and Returns to Industrial R&D*. Washington, D.C.: Public Research Institute.

Grabowski, H. 1968. "The Determinants of Industrial Research and Development: A Study of the Chemical, Drug and Petroleum Industries." *Journal of Political Economy* 76 (2): 292–306.

Griliches, Z. 1964. "Research Expenditures, Education, and the Aggregate Agricultural Production Function." *American Economic Review* 54: 961–74.

______. 1973. "Research Expenditures and Growth Accounting." In *Science and Technology in Economic Growth*, edited by B.R. William. New York: Halstead Press.

______. 1979. "Issues in Assessing the Contribution of Research and Development to Productivity Growth." *Bell Journal of Economics* 10 (1): 92–116.

______. 1980. "Returns to Research and Development in the Private Sector." In *New Developments in Productivity Measurement and Analysis*, edited by J.W. Kendrick and B.N. Vaccara. Chicago: National Bureau of Economic Research.

Hartwick, J., and B. Ewan. 1983. "On Gross and Net Measures of Sectoral R&D Intensity for the Canadian Economy." Kingston: Queen's University. Mimeo.

Hausman, J.A., B.H. Hall, and Z. Griliches. 1984. "Econometric Models for Count Data with an Application to the Patents R&D Relationship." *Econometrica* 52: 909–38.

Howe, J., and D. McFetridge. 1976. "The Determinants of R&D Expenditures." *Canadian Journal of Economics* 9: 57–71.

Leland, H.E. 1974. "Production Theory and the Stock Market." *Bell Journal of Economics* 5 (Spring): 125–44.

Lithwick, N.H. 1969. *Canada's Science Policy and the Economy*. Toronto: Methuen.

Longo, F. 1984. "Industrial R&D and Productivity in Canada." Ottawa: Science Council of Canada.

McFetridge, D.G. 1977. *Government Support of Scientific Research and Development: An Economic Analysis*. Toronto: Ontario Economic Council.

McFetridge, D.G., and J.P. Warda. 1983. *Canadian R&D Incentives: Their Adequacy and Impact*. Toronto: Canadian Tax Foundation.

Mansfield, E. 1965. "Rates of Return from Industrial Research and Development." *American Economic Review* 55: 310–22.

_________.1968. *Industrial Research and Technological Innovation*. New York: Norton.

_________.1980. "Basic Research and Productivity Increase in Manufacturing." American Economic Review 70: 863–73.

Mansfield, E. et al. 1971. *Research and Innovation in the Modern Corporation*. New York: Norton.

_________.1977. "Social and Private Rates of Return from Industrial Innovations." *Quarterly Journal of Economics* 77: 221–40.

Minasian, J. 1969. "Research and Development Production Functions and Rates of Return." *American Economic Review* 59: 80–85.

Nadiri, M.I. 1980. "Contributions and Determinants of Research and Development Expenditures in the U.S. Manufacturing Industries." In *Capital, Efficiency and Growth*, edited by G.M. von Furstenberg. Cambridge, Mass.: Ballinger.

Nadiri, M.I., and G.C. Bitros. 1980. "Research and Development Expenditures and Labor Productivity at the Firm Level: A Dynamic Model." In *New Developments in Productivity Measurement*, edited by J.W. Kendrick and B.N. Vaccara. Chicago: National Bureau of Economic Research.

Nadiri, M.I., and M.A. Schankerman. 1981. "Technical Change, Returns to Scale and the Productivity Slowdown." *American Economic Review* 71: 314–19.

Pakes, A., and Z. Griliches. 1984. "Patents and R&D at the Firm Level: A First Look." In *R&D, Patents and Productivity*, edited by Z. Griliches. Chicago: University of Chicago Press.

Postner, H., and L. Wesa. 1983. Canadian Productivity Growth. Study prepared for the Economic Council of Canada. Ottawa: Minister of Supply and Services Canada.

Raines, F. 1968. "The Impact of Applied Research and Development on Productivity." Working Paper 6814. Seattle: Washington University.

Rasmussen, J. 1973. "Applications of a Model of Indigenous Technical Change to U.S. Industry Data." *Review of Economic Studies* 40: 225–38.

Reinganum, J. 1981. "Dynamic Games of Innovation." *Journal of Economic Theory* 31: 21–41.

Scherer, F.M. 1965. "Firm Size, Market Structure, Opportunity and the Output of Patented Inventions." *American Economic Review* 55: 1097–1125.

_________.1967. "Market Structure and the Employment of Scientists and Engineers." *American Economic Review* 57: 524–31.

_________.1982. "Inter-industry Technology Flows and Productivity Growth." *Review of Economics and Statistics* 64: 627–34.

Schmookler, J. 1966. *Invention and Growth*. Cambridge, Mass.: Harvard University Press.

Schumpeter, J. 1966. *The Theory of Economic Development*. Oxford: Oxford University Press.

Schwartz, S.L. 1983. "An Assessment of the Impact of R&D in Canadian Manufacturing." Vancouver: University of British Columbia.

Spence, M. 1984. "Cost Reduction, Competition and Industry Performance." *Econometrica* 52: 101–21.

Switzer, L. 1984. "R&D and Total Factor Productivity Growth in Canada." Paper presented to a meeting of the Canadian Economics Association, Guelph, June.

Terleckyj, N. 1974. *The Effects of R&D on Productivity Growth of Industries: An Exploratory Study*. Washington, D.C.: National Planning Association.

———. 1980. "Direct and Indirect Effects of Industrial Research and Development on the Productivity Growth of Industries." In *New Developments in Productivity Measurement*, edited by J.W. Kendrick and B.N.Vaccara. Chicago: National Bureau of Economic Research.

2

Canadian Technological Output in a World Context

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DAVID WAITE

Recent attention to the potential effects of microelectronic technology on industry and the working population and media coverage of all areas of scientific advance have fuelled the popular perception of a world on the brink of technological revolution. However, close study suggests that we are not on the verge of a revolution induced by the increasing pace of innovation. On the contrary, patent statistics show that the rate of invention worldwide has declined substantially since 1972 and the British, French and Americans in fact patented fewer inventions annually during the late 1970s than they did in the early 1930s. The revolution, if it arrives, will be a matter of the application rather than the generation of new technology.

This is not to minimize the importance of technology generation as a policy issue. Patent data show us that Japan's economic success has been backed by a remarkable growth in inventive effort, a growth known to be promoted both by Japanese government and industry.

Whether domestically produced or imported, the application of new technology will be essential to Canada's continued competitiveness in world markets. Information concerning the sources of new technology and trends in its development are therefore important to this country's future. The object of this paper is to add to the general understanding of technology generation, and of Canada's performance vis-à-vis the rest of the world, through an analysis of patent data.

The paper covers the following subject areas:

- international trends in the generation of technology as a whole within a fifty-year time frame;

- Canada's relative performance as a world player in the generation and exploitation of new technology;
- Canada's relative position as a technology source — its strengths and weaknesses in the electrical, chemical and mechanical sectors compared to other countries;
- the volatility of technology generation — an investigation at the patent-class level of active, stagnant and neutral technology areas over time; the predictability of technological winners and losers; and
- an exploration of Canada's response to changes in the identity of active technologies compared with those of other countries.

It should be made clear at this stage that the paper does not in any way address the questions of technology adaptation and adoption, which are also important to Canadian productivity. Rather, it deals strictly with the flow of technology available to Canada and the changes in the nature of that flow over time.

The study is based on data drawn from the publications of the World Intellectual Property Organization (WIPO) and from the Canadian Patent Office. The WIPO statistics are used to plot international changes in technology generation as a whole but do not provide a consistent record of trends at a disaggregated level or for smaller countries. For this reason, analyses of trends affecting the newly industrialized countries, and a breakdown of trends among chemical, electrical and mechanical classes based on the international figures, proved unworkable.

Detailed analysis of Canada's relative performance is therefore based on the consistent record of highly disaggregated data available through the Canadian Patent Office. The data used record only the annual number of inventions which are granted patents. For this reason they indicate the rate of flow of new technology onto the market and provide no measure of the stock of usable technology available at any point in time. Some consideration was given to attempting measures of the stocks of available technology by examining figures on patents in force in each year, rather than on new patents granted. The attempt was not pursued, both because of incomplete data and because this indicator was regarded as unreliable for a number of reasons. Among these were the problem of differing terms and renewal regulations in different countries; the fact that some items of technology remain widely used despite an expired patent term; and the fact that some items, though still protected by patents, will already have been outdated by advances in the same field.

Finally, it should be acknowledged that patent statistics by no means provide watertight measures of technology generation. Some of the claimed weaknesses are that not all technologies are patentable and that propensities to patent may vary from industry to industry.[1] With respect to the first weakness, the most notable technologies which are not

patentable in Canada are computer software and some forms of biotechnology. With respect to the second weakness, it is claimed that some electrical technologies are not patented because of the slowness of the patent-granting process. This claim, however, ignores the market power which can result from "patent pending," and indeed electrical technology producers such as IBM, General Electric and NV Philips are among the ten largest users of the Canadian patent system. It should be pointed out at the same time that patent data also have a number of strengths, particularly in the present context. Most other data, for example, are collected by survey, with all the attendant problems concerning coverage and reliability. As well, patent data are real measures which facilitate international and temporal comparisons without accounting for the difficulties inherent in exchange rate and inflation rate measurement.

Trends in Worldwide Technology Generation

This section draws on the hundred-year record of world patenting activity recently published by WIPO (1983) to document changes in the international rates of technology generation and diffusion over sample periods between 1925 and the present. The period between the two world wars is reviewed only briefly to provide a perspective on the changes which have occurred in the area in recent years.

Rates of Patenting Worldwide

Viewed in isolation, the figures presented in Table 2-1 below, which shows total patents granted worldwide, appear to confirm the popular notion of a rapid growth in technological change in the years since World War II. The annual number of patents granted between the wars reached its highest level at 213,720 in 1931. A period of low activity occurred during the postwar reconstruction period. The 1931 figure, however, had been surpassed by 1955, and in 1972 the rate of patenting was 2.26 times its highest level of the interwar period. Moreover, by 1982, after a decade of economic uncertainty, patents were still being granted at approximately twice the 1931 rate.

Invention and Diffusion

However, it is important to note that the data in Table 2-1 do not simply represent rates of inventive activity. The figures also reflect the fact that an inventor is granted a separate patent by every country in which he patents his original invention.

Since patenting in a country other than that of the patentee's residence indicates an intention to exploit an invention in the second country, the

figures presented can also be said to indicate two things: rates of invention plus rates of technology diffusion around the world.[2] The difficulty is that the figures do not show where the effects of diffusion end and those of invention begin. The two effects could be separated easily if worldwide figures were available showing numbers of patents granted by countries only to their own residents. Unfortunately, the WIPO record is incomplete in this respect.

However, to provide an indication of the separate trends in invention and diffusion based on available information, Table 2-2 records changes in patenting rates for seven trading nations over sample periods between 1925 and 1982. The table shows figures for three years in the interwar period, as a basis for comparison with the years of strong growth during the 1960s and the periods of decline and fluctuation which began in 1973. For each country, the left-hand column shows total patents granted and the right shows patents granted to its own nationals. The final three columns show total patents granted by all seven countries, totals granted to own nationals, and the latter expressed as a percentage of the former.

Rates of Invention

The first conclusion suggested by these figures is that the notion of a quickening pace of technological change is in fact erroneous. The figures may mask the real pace of change somewhat since, as already noted, not all industries patent all their inventions. Nevertheless, among the seven

TABLE 2-1 Total Patents Granted Worldwide, 1925–82

Year	Patents Granted	Year	Patents Granted
1925	174,999	1964	339,431
		1965	374,419
1930	207,426	1966	415,156
		1967	454,710
1935	168,417	1968	424,774
		1969	405,611
1940	135,252	1970	420,416
		1971	460,877
1945	82,052	1972	482,356
		1973	447,911
1950	161,594	1974	425,637
		1975	412,117
1955	216,187	1976	427,155
		1977	442,430
1960	278,045	1978	400,305
1961	295,415	1979	386,045
1962	298,264	1980	422,961
1963	312,501	1981	423,348
		1982	425,154

Source: World Intellectual Property Organization (WIPO), *100 Years of Industrial Property Statistics*, (Geneva, 1983).

TABLE 2-2 Patents Granted by Seven Countries 1925–82 in Total and to Own Nationals

	Canada		France		Germany[a]		Japan		Netherlands		United Kingdom		United States		Seven-Country Totals		
	Total	Own Nationals	Total	Own Nationals	Total	Own Nationals	Total	Own Nationals	Total	Own Nationals	Total	Own Nationals	Total	Own Nationals	Total Patents	Total to Own Nationals	Per-cent
1925	9,508	1,302	18,000	10,832	15,877	11,653	5,088	3,590	1,648	368	17,199	N.A.	46,432	41,085	—	—	—
1930	10,401	1,169	24,000	11,266	26,737	19,597	4,976	3,366	2,322	403	20,888	9,678	45,226	39,141	134,550	84,620	62.9
1935	8,713	885	18,000	9,215	16,139	12,168	4,766	3,816	2,800	606	17,675	N.A.	40,663	34,683	—	—	—
1963	21,225	1,194	38,145	13,230	15,542	9,767	23,303	14,937	3,562	674	30,148	N.A.	45,808	37,291	—	—	—
1964	23,230	1,060	39,305	13,673	19,597	12,081	23,700	15,103	3,288	631	32,619	N.A.	47,376	38,410	—	—	—
1965	23,476	1,116	41,800	14,570	16,780	10,011	26,905	17,797	2,350	451	33,864	N.A.	62,857	50,332	—	—	—
1966	24,258	1,131	43,950	14,881	22,598	13,095	26,315	17,373	2,261	394	37,272	N.A.	68,406	54,634	—	—	—
1967	24,432	1,222	46,995	15,246	19,871	11,520	20,773	13,877	2,335	322	38,999	N.A.	65,652	51,274	—	—	—
1968	25,836	1,263	47,990	15,627	21,169	12,143	27,972	18,576	2,324	278	43,038	N.A.	59,102	45,782	—	—	—
1969	27,703	1,433	32,020	10,288	22,623	12,432	27,657	18,787	2,152	242	38,790	9,807	67,557	50,395	218,502	103,984	47.6
1970	28,981	1,461	26,117	8,359	12,887	6,386	30,879	21,404	2,508	284	40,995	10,343	64,427	47,073	206,794	95,310	46.1
1971	29,193	1,395	51,456	13,696	18,149	8,295	36,447	24,795	2,714	318	41,554	10,376	78,318	55,988	257,831	114,863	44.5
1972	29,242	1,587	46,217	10,767	20,600	9,642	41,454	29,101	2,886	334	42,794	10,116	74,808	51,575	258,001	113,062	43.8
1973	26,847	1,486	27,939	10,817	23,934	11,191	42,328	30,937	3,268	383	39,844	9,357	74,139	51,501	238,299	115,672	48.5
1974	20,844	1,200	24,725	9,282	20,539	9,793	39,626	30,873	3,386	423	37,808	8,971	76,275	50,643	223,203	111,185	50.0
1975	20,688	1,336	14,320	4,962	18,290	9,077	46,728	36,992	3,845	429	40,689	9,120	71,994	46,603	216,554	108,519	50.1
1976	21,440	1,293	29,754	8,420	20,965	10,395	40,317	32,465	3,589	370	39,797	8,855	70,236	44,162	226,098	105,960	46.9
1977	21,130	1,260	31,045	8,361	21,749	10,815	52,608	43,047	3,692	396	36,549	7,722	65,269	41,383	232,042	112,984	48.7
1978	20,995	1,352	30,530	8,083	23,514	11,581	45,504	37,648	3,325	432	40,823	8,464	66,102	40,979	230,973	108,539	47.0
1979	22,796	1,369	24,618	6,846	22,534	10,895	44,104	34,863	3,458	455	20,800	4,182	48,853	30,605	187,163	89,205	47.7
1980	22,894	1,450	28,060	8,438	20,188	9,826	46,106	38,032	3,324	417	23,804	5,158	61,827	37,152	206,203	100,473	48.7
1981	24,165	1,526	21,477	6,855	13,429	6,537	50,904	42,060	3,058	397	22,924	6,076	65,770	39,225	201,727	102,695	50.9
1982	22,447	1,386	23,944	7,764	16,306	8,279	50,601	42,223	6,653	618	29,590	4,686	57,889	33,896	207,430	98,852	47.7

Source: World Intellectual Property Organization (WIPO), *100 Years of Industrial Property Statistics*, Geneva, 1983.

a. Figures from 1963 on, refer to Federal Republic of Germany only.

countries shown, the rate of patenting by own residents grew by only 36 percent between the sample interwar year of 1930 and the peak year of 1973. Moreover, in 1982 the rate of patenting was only 16 percent greater than in 1930.

The picture is perhaps even more surprising for the individual countries on the list. Japan alone shows a strong trend towards growth in inventiveness, with rates of patenting by Japanese nationals rising steadily in the last three decades to approximately ten times their prewar level. France and the United States, on the other hand, recorded their highest rates in the mid-1960s at 138 and 140 percent of the 1930 levels respectively and have since slipped back to only 69 and 87 percent of the prewar figures. Meanwhile the United Kingdom, having reached 107 percent of the 1930 rate in 1971, by 1982 had fallen to the point where inventions were being patented at less than half the interwar rate. In contrast to the general picture of fluctuation and international change, Canada's performance as a source of inventions has been relatively stable. Rates of patenting in Canada by Canadians reached 136 percent of their 1930 level in 1972, came close to this level again in 1981, and in 1982 were still at 118 percent.

Rates of Diffusion

It would appear then that the major portion of growth in world patenting up to 1972 was attributable to the diffusion of technology internationally rather than to rapidly growing rates of innovation. While international patenting rates grew by a factor of 2.2 between 1930 and the peak year of 1972, the number of individual patented inventions among the seven countries shown grew by a factor of only 1.36 — from 84,620 in 1930 to 115,672 in 1973.

It is worth noting that despite the growth in diffusion up to 1972, patenting has continued to be concentrated among the major industrial countries. The seven countries shown granted 65 percent of the world's patents in 1930, and this level had slipped only to 50 percent in 1972 and 49 percent in 1982.

Conclusion

It would seem that the popular notion of an increasing pace of technological change is unfounded. In fact, worldwide rates of invention had increased to a maximum level only 36 percent above their interwar level in 1972 and have decreased considerably from this peak in the intervening years. Among the major trading nations, Japan alone continues to increase the number of inventions it patents annually, while the United States, France and Britain now patent considerably fewer inventions than they did in 1930. Meanwhile, Canada's inventive record has

remained relatively stable in world terms, following closely the international pattern of postwar growth, and remaining comfortably above interwar levels into the early 1980s.

Canada's Performance in the Generation and Exploitation of New Technology

Five measures are used here to rate Canada's performance as an originator and as an exploiter of new technology relative to six other trading nations — France, West Germany, Japan, the Netherlands, Great Britain and the United States.

- The section deals firstly with the proportion of world patents granted by Canada and by the other countries as an indication of the technological capacity of each.
- Secondly, the proportion of world patents granted by Canada to Canadians is compared to similar proportions for the other countries.
- Thirdly, the section compares shares of patents granted to residents of Canada and of the other nations, to show which countries are gaining and which are losing ground in the international exploitation of their own technology.
- Next, the section analyzes the different propensities of the seven countries to exploit their own technology abroad, by measuring the proportion of domestic to foreign patents granted to residents of each.
- Finally, countries' patenting levels are shown in relation to the sizes of their respective national economies.

The section covers the eleven-year period between 1972 and 1982, for which the most complete international data are available, and deals with the patenting records of the seven countries. In the first three measures above, the authors considered showing individual countries' performances in terms of their shares of the seven-country total in addition to their world shares. This extra step yielded significant information only in the third measure and has therefore been omitted in the other cases.

Levels of Patenting in Canada and Other Countries

The number of patents granted by a country is a combined indicator of its capacity for invention and of the desire of foreign nationals to protect their inventions within it. Since most patented inventions are used by business, rather than directly in the retail market, the number of foreign-origin patents granted in a country will also indicate its general capacity to make use of new technology. Table 2-3 shows total patents granted by Canada and six other countries, followed by the percentage these represent of total world patents.

TABLE 2-3 Patents Granted in Seven Countries as a Proportion of World Total Patents

Year	Total World Patents	Canada Total Patents	Canada Percent	France Total Patents	France Percent	Germany Total Patents	Germany Percent	Japan Total Patents	Japan Percent	Netherlands Total Patents	Netherlands Percent	United Kingdom Total Patents	United Kingdom Percent	United States Total Patents	United States Percent
1972	482,356	29,242	6.1	46,217	9.6	20,600	4.3	41,454	8.6	2,886	0.6	42,794	8.9	74,808	15.5
1973	447,911	26,847	6.0	27,939	6.2	23,934	5.3	42,328	9.4	3,268	0.7	39,844	8.9	74,139	16.5
1974	428,639	20,844	4.9	24,725	5.8	20,539	4.8	39,626	9.2	3,386	0.8	37,808	8.8	76,275	17.8
1975	412,119	20,688	5.0	14,320	3.5	18,290	4.4	46,728	11.3	3,845	0.9	40,689	9.9	71,994	17.5
1976	427,155	21,440	5.0	29,754	7.0	20,965	4.9	40,317	9.4	3,589	0.8	39,797	9.3	70,236	16.4
1977	442,430	21,130	4.8	31,045	7.0	21,749	4.9	52,608	11.9	3,692	0.8	36,549	8.3	65,269	14.8
1978	406,305	20,995	5.2	30,530	7.5	23,514	5.8	45,504	11.2	3,325	0.8	40,823	10.0	66,102	16.3
1979	386,045	22,796	5.9	24,618	6.4	22,534	5.8	44,104	11.4	3,458	0.9	20,800	5.4	48,853	12.5
1980	422,969	22,894	5.4	28,060	6.6	20,188	4.8	46,106	10.9	3,324	0.8	23,804	5.6	61,827	14.6
1981	423,348	24,165	5.7	21,477	5.1	13,429	3.2	50,904	12.0	3,058	0.7	22,924	5.4	65,770	15.5
1982	425,154	22,447	5.3	23,944	5.6	16,306	3.8	50,601	11.9	6,653	1.6	29,590	7.0	57,889	13.6

Source: World Intellectual Property Organization (WIPO). *100 Years of Industrial Property Statistics*. (Geneva. 1983).

The 1970s was a time of considerable change in the patterns of international patenting. The large U.S. share of the world's patents declined somewhat, from a high point of 17.8 percent in 1974 to a 1982 level of 13.6 percent, while the Japanese share was generally on the increase, rising from 8.6 percent in 1972 to a maximum of 12.0 percent in 1981 and ending at 11.9 percent in 1982. Over the same period the French and British shares, while unusually high in 1978, also generally declined. Figures for the Netherlands, West Germany and Canada show fluctuation without pronounced upward or downward trends, though Germany and Canada ended the period with slightly lower shares while the final figure for the Netherlands was markedly higher than in previous years. The United States, France and Great Britain are apparently becoming less important places to patent while, as might be expected, Japan is becoming steadily more important.

Canada's importance meanwhile remains relatively stable in international terms. However, two points are worth noting here. Firstly, Canada is the recipient of a large number of foreign patents. In 1982 it granted 21,620 patents to foreign nationals, the third highest figure after the United States with 23,993 and Britain with 24,904. Secondly, although this number is high, a disproportionate percentage are of U.S. origin. Table 2-4 indicates the number of foreign-origin patents in six countries, the number of patents of U.S. origin, and the percentage of foreign-origin patents held by U.S. applicants in 1982.

Despite this high proportion of U.S. patents, however, Canada still attracts more interest from elsewhere in the world than do West Germany and Japan. Moreover, the proportion of U.S.–origin patents has been in decline in recent years, falling to its present level from 64 percent in 1975.

TABLE 2-4 U.S. Patents as a Proportion of Foreign-Origin Patents in 1982

	Total Foreign Patents	U.S.–Origin Patents	Percent
Canada	21,620	12,595	58
France	16,180	4,504	28
West Germany	8,027	2,531	32
Japan	8,378	4,101	49
Netherlands	6,035	1,457	24
United Kingdom	24,904	7,831	31

Sources: World Intellectual Property Organization (WIPO). *100 Years of Industrial Property Statistics*, (Geneva, 1983), and *WIPO Intellectual Property Statistics 1982* (Geneva).

Generation of Technology by Canada and Other Countries

Figures in Table 2-5 showing numbers of patents granted by the seven countries to their own residents tend to conform to the patterns seen above. Against a background of generally reduced patenting activity worldwide, the United States, United Kingdom and France granted smaller shares of the world's patents to their own residents in 1982 than in 1972, while Japan's share grew and the shares of Canada, the Netherlands and West Germany remained about the same.

The clearest trends are to be seen in the growth of Japanese domestic patenting, with a rise in absolute numbers from 29,101 and 42,223 and a rise in world share from 6.0 percent to 9.9 percent, and in the even more rapid decline in patenting at home by the British, whose absolute numbers and world share were both halved over the eleven-year period.

Meanwhile, domestic patenting in the United States, France and West Germany has been subject to considerable fluctuation. All three countries ended the period with somewhat smaller shares of the world total than when they began, although the decline was only marginal in the case of Germany.

Finally, despite a decline in the absolute number of patents granted to them, Canadians patenting at home have maintained a small but stable share of the world's total activity at 0.3 percent.

International Patenting by Residents of Seven Countries

An examination of levels of patenting abroad by residents of the same seven countries presents a somewhat less clear picture of Canadian performance. Table 2-6 below shows numbers of patents granted to residents of each country by all other countries and the proportion each represents of total world patents. Table 2-7 shows the same figures but as a proportion of the seven-country totals.

When shares of world patents are considered, once again the Japanese share of the totals can be seen to have grown over the period examined, although the upward trend has been subject to considerable fluctuation. Once again, the U.S., British and French shares have fallen, with Britain faring worst. However, in this case, the overall shares of West Germany, the Netherlands and Canada have also been subject to marked, if somewhat erratic, downward trends. The Canadian share of foreign patenting has historically been very small, less than 1 percent of total world patents. This proportion has been falling slowly but consistently since 1975. To put this in a clearer perspective, it can be said that Canada's 1982 share was 74 percent of its world share in 1972, while for the other countries concerned the proportions were France 84 percent, West Germany 72 percent, Japan 139.0 percent, the Netherlands 81.5 percent, United Kingdom 58 percent, and the United States 71 percent.

TABLE 2-5 Patents Granted by Seven Countries to Their Own Residents as a Proportion of World Total Patents

		Canada		France		Germany		Japan		Netherlands		United Kingdom		United States	
Year	Total World Patents	Total Patents	Percent	Total Patents	Percent	Total Patents	Percent	Total Patents	Percent	Total Patents	Percent	Total Patents	Percent	Total Patents	Percent
1972	482,358	1,587	0.3	10,767	2.2	9,642	2.0	29,101	6.0	334	0.1	10,116	2.1	51,515	10.7
1973	447,919	1,486	0.3	10,817	2.4	11,191	2.5	30,937	6.9	383	0.1	9,357	2.1	51,501	11.5
1974	428,639	1,200	0.3	9,282	2.2	9,793	2.3	30,873	7.2	423	0.1	8,971	2.1	50,643	11.8
1975	412,119	1,336	0.3	4,962	1.2	9,077	2.2	36,992	9.0	429	0.1	9,120	2.2	46,603	11.3
1976	427,155	1,293	0.3	8,420	2.0	10,395	2.4	32,465	7.6	370	0.1	8,855	2.1	44,162	10.3
1977	442,430	1,260	0.3	8,361	1.9	10,815	2.4	43,047	9.7	396	0.1	7,722	1.7	41,383	9.3
1978	406,305	1,352	0.3	8,083	2.0	11,581	2.8	37,648	9.3	432	0.1	8,464	2.1	40,979	10.1
1979	386,045	1,369	0.3	6,846	1.8	10,895	2.8	34,863	9.0	455	0.1	4,182	1.1	30,605	7.9
1980	422,969	1,450	0.3	8,438	2.0	9,826	2.3	38,032	9.0	417	0.1	5,158	1.2	37,152	8.8
1981	423,348	1,526	0.4	6,855	1.6	6,537	1.5	42,080	9.9	397	0.1	6,076	1.4	39,225	9.3
1982	425,154	1,386	0.3	7,764	1.8	8,279	1.9	42,223	9.9	618	0.1	4,686	1.1	33,896	8.0

Source: World Intellectual Property Organization (WIPO), *100 Years of Industrial Property Statistics*, (Geneva, 1983).

TABLE 2-6 International Patenting by Residents of Seven Countries as a Proportion of World Total Patents

Year	Total World Patents	Canada		France		Germany		Japan		Netherlands		United Kingdom		United States	
		Total Patents	Percent	Total Patents	Percent	Total Patents	Percent	Total Patents	Percent	Total Patents	Percent	Total Patents	Percent	Total Patents	Percent
1972	482,358	3,134	0.65	18,533	3.8	55,370	11.5	19,674	4.1	8,683	1.80	20,916	4.3	90,015	18.7
1973	447,919	3,201	0.71	16,892	3.8	45,975	10.3	17,694	3.9	7,284	1.62	17,341	3.9	72,341	16.1
1974	428,639	2,930	0.68	14,392	3.4	39,752	9.3	18,175	4.2	6,249	1.45	15,050	3.5	63,027	14.7
1975	412,119	2,950	0.72	15,339	3.7	39,500	9.6	18,528	4.5	5,900	1.43	14,558	3.5	61,452	14.9
1976	427,155	2,916	0.68	17,093	4.0	44,407	10.4	21,429	5.0	7,238	1.69	16,785	3.9	47,050	11.0
1977	442,430	2,963	0.67	17,448	3.9	44,615	10.1	21,308	4.8	7,431	1.67	15,197	3.4	56,397	12.7
1978	406,305	2,745	0.68	15,116	3.7	36,911	9.1	21,766	5.4	6,611	1.63	13,135	3.2	62,680	15.4
1979	386,045	2,098	0.54	12,733	3.3	31,854	8.2	17,917	4.6	5,885	1.52	11,255	2.9	56,019	14.5
1980	422,969	2,255	0.52	13,196	3.1	33,987	8.0	20,986	5.0	6,356	1.50	11,944	2.8	56,525	13.4
1981	423,348	2,053	0.48	11,490	2.7	30,698	7.2	19,649	4.6	5,334	1.26	9,974	2.4	49,637	11.7
1982	425,154	2,041	0.48	13,556	3.2	35,142	8.3	24,326	5.7	6,172	1.45	10,496	2.5	56,567	13.3

Sources: World Intellectual Property Organization (WIPO), *100 Years of Industrial Property Statistics*, (Geneva, 1983), and *WIPO Intellectual Property Statistics 1972–1982*, (Geneva, 1983).

TABLE 2-7 International Patenting by Residents of Seven Countries as a Proportion of the Seven-Country Totals

Year	Seven Country Totals	Canada Total Patents	Canada Percent	France Total Patents	France Percent	Germany Total Patents	Germany Percent	Japan Total Patents	Japan Percent	Netherlands Total Patents	Netherlands Percent	United Kingdom Total Patents	United Kingdom Percent	United States Total Patents	United States Percent
1972	216,325	3,134	1.4	18,533	8.6	55,370	25.6	19,674	9.1	8,683	4.0	20,916	9.7	90,015	41.6
1973	180,728	3,201	1.8	16,892	9.3	45,975	25.4	17,694	9.8	7,284	4.0	17,341	9.6	72,341	40.0
1974	159,575	2,930	1.8	14,392	9.0	39,752	24.9	18,175	11.4	6,249	3.9	15,050	9.4	63,027	39.5
1975	158,227	2,950	1.8	15,339	9.7	39,500	25.0	18,528	11.7	5,900	3.7	14,558	9.2	61,452	38.8
1976	156,918	2,916	1.9	17,093	10.9	44,407	28.3	21,429	13.6	7,238	4.6	16,785	10.7	47,050	30.0
1977	165,359	2,963	1.8	17,448	10.6	44,615	27.0	21,308	12.9	7,431	4.5	15,197	9.2	56,397	34.1
1978	158,964	2,745	1.7	15,116	9.5	36,911	23.2	21,766	13.7	6,611	4.2	13,135	8.3	62,680	39.4
1979	137,761	2,098	1.5	12,733	9.2	31,854	21.9	17,917	13.0	5,885	4.3	11,255	8.2	56,019	40.7
1980	145,249	2,255	1.5	13,196	9.1	33,987	23.4	20,986	14.4	6,356	4.4	11,944	8.2	56,525	38.9
1981	128,835	2,053	1.6	11,490	8.9	30,698	23.8	19,649	15.2	5,334	4.1	9,974	7.7	49,637	38.5
1982	148,300	2,041	1.4	13,556	9.1	35,142	23.7	24,326	16.4	6,172	4.2	10,496	7.1	56,567	38.1

Sources: World Intellectual Property Organization (WIPO), *100 Years of Industrial Property Statistics*, (Geneva, 1983), and *WIPO Intellectual Property Statistics, 1972–1982*, (Geneva, 1983).

However, viewed in the context of the seven-country group (Table 2-7), individual countries' performances for the most part appear more stable. Canada began and ended the ten-year period with the same share of the group total. Meanwhile the shares of West Germany, the United States and the United Kingdom fell to 92, 92 and 73 percent, respectively, of their 1972 shares and the Dutch, French and Japanese shares rose to 105, 106 and 180 percent.

These generally smaller fluctuations suggest a shift away from the seven countries as the major source of world patents. The implication is apparently confirmed by Table 2-8, which is an amalgamation of figures from Tables 2-2, 2-6 and 2-7.

A major portion of the decline in the seven countries' share of world patenting is clearly the result of a fall in foreign patenting by their residents. Meanwhile, not only the share but also the numbers of patents granted to the remainder of the countries can be seen to have grown, despite an overall decline of 12 percent in world patenting.

Further investigation shows this shift to be due almost entirely to a rise in domestic patenting within the Soviet Union from 32,523 patents granted in 1972 to 89,304 in 1982. The number of patents applied for at home by Soviet residents rose in the same period by a much smaller proportion from 128,294 to 158,972, while the relatively modest levels of Soviet patenting abroad declined during the same period from 3,171 to 2,132. These figures suggest a change in Soviet policy with regard to domestic patenting as opposed to a marked rise in the real level of invention within the Soviet Union.

Propensity to Exploit Domestic Technology Internationally

One means of comparing countries' propensities to exploit their technology internationally is to examine the ratio of patents taken out abroad to patents taken out at home by residents of each country. An analysis of this kind shows that some countries invest many times more effort in patenting their technology abroad than do others, regardless of the scale of their respective inventive efforts. Tables 2-9 and 2-10 below show total foreign and domestic patenting by residents of the seven countries and the relevant ratios. The results shown for the Netherlands and Japan are perhaps most striking here.

Japan is an exceptional case in that it rates poorly in terms of its foreign to domestic patenting ratio and yet is known to be extremely adroit in the international exploitation of its domestically produced technology. Part of the reason for this low ratio is a high level of domestic patenting, resulting from systematic efforts by government and industry to promote invention. This applies as much to employees on the shop floor and in management as to technical staff. The low ratio is also the result of Japanese patent regulations. Japanese priority rules encourage

TABLE 2-8 Patents Granted to the Seven Countries as a Proportion of Patents Granted to All Countries

	1972		1982	
	Total	% of World Total	Total	% of World Total
Foreign patents granted to residents of seven countries	216,325	45	148,300	35
Domestic patents granted to residents of seven countries	113,062	23	98,852	23
Total patents granted to residents of seven countries	329,387	68	247,152	58
Total patents granted to residents of all other countries	152,963	32	178,002	42
Total world patents	482,350	100	425,154	100

Sources: World Intellectual Property Organization (WIPO), *100 Years of Industrial Property Statistics* (Geneva, 1983), and *WIPO Intellectual Property Statistics 1972* and *1982* (Geneva).

TABLE 2-9 International Patenting as a Proportion of Domestic Patenting by Residents of Seven Countries

	Canada			France			Germany			Japan			Netherlands			United Kingdom			United States		
Year	Total International Patents	Total Domestic Patents	Ratio	Total International Patents	Total Domestic Patents	Ratio	Total International Patents	Total Domestic Patents	Ratio	Total International Patents	Total Domestic Patents	Ratio	Total International Patents	Total Domestic Patents	Ratio	Total International Patents	Total Domestic Patents	Ratio	Total International Patents	Total Domestic Patents	Ratio
1972	3,134	1,587	1.97	18,533	10,767	1.72	55,370	9,642	5.74	19,674	29,101	0.67	8,683	334	25.99	20,916	10,116	2.06	90,015	51,515	1.74
1973	3,201	1,486	2.15	16,892	10,817	1.56	45,975	11,191	4.10	17,694	30,931	0.57	7,284	383	19.01	17,341	9,357	1.85	72,341	51,501	1.40
1974	2,930	1,200	2.44	14,392	9,282	1.55	39,752	9,793	5.08	18,175	30,873	0.59	6,249	423	14.77	15,050	8,971	1.67	63,027	50,643	1.24
1975	2,950	1,336	2.20	15,339	4,962	3.09	39,500	9,077	4.35	18,538	36,972	0.50	5,900	429	13.75	14,558	9,120	1.59	61,452	46,603	1.32
1976	2,916	1,293	2.25	17,093	8,420	2.03	44,407	10,395	4.27	21,429	32,465	0.66	7,238	370	19.56	16,785	8,855	1.89	47,050	44,162	1.06
1977	2,963	1,260	2.35	17,448	8,361	2.08	44,615	10,815	4.12	21,308	43,047	0.49	7,431	396	18.76	15,177	7,722	1.96	56,377	41,383	1.36
1978	2,745	1,352	2.03	15,116	8,083	1.87	36,911	11,581	3.18	21,766	37,648	0.57	6,611	432	15.30	13,135	8,464	1.55	62,680	40,979	1.52
1979	2,098	1,369	1.52	12,733	6,846	1.85	31,854	10,895	2.92	17,917	34,863	0.51	5,885	455	12.93	11,255	4,182	2.69	56,019	30,605	1.83
1980	2,255	1,450	1.55	13,196	8,438	1.36	33,987	9,826	3.64	20,986	38,032	0.55	6,356	417	15.24	11,944	5,158	2.31	56,525	37,152	1.52
1981	2,053	1,526	1.34	11,490	6,855	1.67	30,698	6,537	4.69	19,649	42,080	0.46	5,334	397	13.43	9,974	6,076	1.64	49,637	39,225	1.26
1982	2,041	1,386	1.47	13,556	7,764	1.74	35,142	8,279	4.24	24,326	42,223	0.57	6,172	618	9.98	10,496	4,686	2.23	56,567	33,896	1.66

Source: World Intellectual Property Organization (WIPO), *WIPO Intellectual Property Statistics 1972 to 1982*, (Geneva, 1983).

early filing for relatively unrefined inventions, followed by patents for later stages in the refinement process. Moreover, until recently an inventor was required to take out separate patents for each claim associated with an invention, rather than a single patent with a number of appended claims as is customary in other countries.

At the other end of the scale, the Netherlands, which has a comparatively low rate of domestic inventive activity, clearly exploits its technology aggressively on the international market, since it presently takes out ten times as many patents abroad as it does at home. Meanwhile, the United States with its high number of domestic patents maintains a relatively low ratio but still dominates the international scene in terms of volume of patents granted.

Canada, by comparison, rates relatively poorly, with a foreign-to-domestic-patenting ratio in the last four years of about 1.5. This ratio appears even less impressive when adjusted for the effects of Canadian patenting in the United States, as in Table 2-10. Patents taken out in the United States in recent years account for approximately half of Canada's total foreign patents. None of the other countries analyzed in the table was in a similar position vis-à-vis a large trading neighbour.

One may speculate that Canada's rather poor propensity to exploit and protect its technology abroad is partly the result of the large and convenient U.S. market next door, and partly a consequence of a branch-plant economy, whose inventions are exploited internationally by multinational companies based elsewhere. Whatever the causes, Canada would appear not to be faring well in the international competition to secure markets for new inventions. Further research is needed to determine precisely why this is the case.

Patenting Levels Relative to GNP

While this paper makes no attempt to establish causal links between patenting and national economy activity, GNP is used in Table 2-11 as an additional measure against which to judge patenting levels in the seven countries. For each country the table shows GNP in billions of U.S. dollars, number of patents granted to own residents at home, to foreign residents, and to own residents abroad, and indexes these numbers to GNP.[3]

Given the diversity and disparity in sizes of the economies compared, any interpretation of this index must be regarded with caution. The United States, for example, with its high levels of patenting, fares only modestly when these levels are indexed to a GNP far larger than any other. Nevertheless the figures for the most part confirm the conclusions suggested by other measures used in the section. For example, the Netherlands is again shown to be a small-scale producer of technology but a strong exporter, along with West Germany. The larger scale of

TABLE 2-10 International Patenting, Other than in the United States, by Residents of Six Countries

	Canada			France			West Germany			Japan			Netherlands			United Kingdom		
Year	International Total	Domestic Total	Ratio	International Total	Domestic Total	Ratio	International Total	Domestic Total	Ratio	International Total	Domestic Total	Ratio	International Total	Domestic Total	Ratio	International Total	Domestic Total	Ratio
1972	1,890	1,587	1.19	16,302	10,767	1.51	49,642	9,642	5.15	14,520	29,101	0.49	8,007	334	23.97	17,752	10,116	1.75
1973	1,856	1,486	1.24	14,749	10,817	1.36	40,387	11,191	3.61	12,755	30,931	0.41	6,598	383	17.22	14,490	9,357	1.55
1974	1,605	1,200	1.33	11,827	9,282	1.27	33,596	9,793	3.43	12,286	30,873	0.39	5,516	423	13.04	11,905	8,971	1.32
1975	1,621	1,336	1.21	12,973	4,962	2.61	33,431	9,077	3.68	12,199	36,972	0.32	5,288	429	12.32	11,497	9,120	1.26
1976	1,700	1,293	1.31	14,676	8,420	1.74	38,164	10,395	3.67	14,887	32,465	0.46	6,448	370	17.53	13,772	8,855	1.56
1977	1,712	1,260	1.35	15,344	8,361	1.83	39,030	10,815	3.60	15,103	43,047	0.35	6,722	396	16.97	12,521	7,722	1.62
1978	1,473	1,352	1.08	12,990	8,083	1.60	31,005	11,581	2.67	14,852	37,648	0.39	5,951	432	13.77	10,368	8,464	1.22
1979	1,206	1,369	0.88	11,200	6,846	1.63	27,456	10,895	2.52	12,848	34,863	0.36	5,385	455	11.83	9,414	4,182	2.25
1980	1,148	1,450	0.79	11,101	8,438	1.31	28,220	9,826	2.87	13,813	38,032	0.36	5,074	417	13.67	9,504	5,158	1.84
1981	918	1,526	0.60	9,309	6,855	1.35	24,448	6,537	3.73	11,259	42,080	0.26	4,682	397	11.97	7,501	6,076	1.23
1982	1,051	1,386	0.75	11,581	7,764	1.49	29,733	8,279	3.59	16,177	42,223	0.38	5,553	618	8.99	8,361	4,686	1.78

Sources: World Intellectual Property Organization (WIPO), *100 Years of Industrial Property Statistics*, and *WIPO Intellectual Property Statistics 1972–1982*, (Geneva, 1983).

TABLE 2-11 Patents Compared to GNP in 1982

	GNP (US $ billion)	Domestic Patents to Own Residents	Per billion GNP	Domestic Patents to Foreign Residents	Per billion GNP	Foreign Patents to Own Residents	Per billion GNP
Canada	232.21	1,386	5.97	21,061	90.7	2,041	8.97
France	420.91	7,764	18.44	16,180	38.4	13,556	32.19
West Germany	605.01	8,279	13.68	8,009	13.2	35,142	58.08
Japan	1,102.46	42,223	41.72	8,378	8.3	24,326	24.04
Netherlands	122.27	618	5.06	6,035	49.5	6,172	50.59
United Kingdom	393.06	4,686	11.92	24,904	63.4	10,496	26.70
United States	2,650.30	33,896	12.97	23,993	9.1	56,576	21.35

Source: International Monetary Fund, *International Financial Statistics Yearbook 1983* (Washington, D.C.), and World Intellectual Property Organization, *WIPO Intellectual Property Statistics 1982* (Geneva).

domestic patenting in Japan and of foreign patenting in Britain are also confirmed.

Table 2-11 highlights Canada's relatively small-scale domestic patenting level and poor propensity to patent abroad. At 5.97 patents per billion of GNP, Canadian domestic patenting occurs at roughly half the rates of Britain, West Germany and the United States, and at one-third that of France. Canada's index of domestic patenting is only slightly above that of the Netherlands with its much smaller economy. Our index of foreign patenting is the lowest among the countries shown, and only one-third that of Japan, the next lowest country on the list.

Conclusions

In a period of considerable international change, Canada holds a relatively stable though not a strong position with regard to its capacity to generate new technology. Canada's capacity to use new technology, indicated by the number of foreign-origin patents granted here, would seem to be both stable and high. At the same time, however, Canadians appear to fare poorly in exploiting their own technology abroad. Further research is needed to determine the reasons for this.

While the United States, Britain and France granted markedly declining shares of the world's patents in the 1970s and Japan's share rose considerably, the Canadian portion remained relatively stable at between 5 and 6 percent.

Similarly, the United States, Britain and France granted fewer patents and smaller shares of the world total to their own residents, while Japan granted an increasing share, and the Canadian position remained static. On the other hand, Canada has been responsible for only a tiny portion of the world's inventions. In 1982, Canada granted only 0.3 percent of the world's total number of patents to its own inventors, while the United States granted 8.0 percent, Japan 9.9 percent, West Germany 1.9 percent and France 1.8 percent. In other words, Canada is a relatively consistent but small-scale producer of new technology.

The major trading nations, with the exception of Japan, patented abroad on a declining scale during the 1970s. The portion of world patents granted to residents of the seven countries in countries other than their own fell from 44 percent in 1972 to 34 percent in 1982. Regardless of this general decline, Canada's propensity to patent — and by implication to exploit — its own technology abroad remains poor compared to Germany, Britain and the Netherlands, for example. The Netherlands in particular, while patenting only a small number of inventions domestically, takes out ten times more patents abroad than at home. Canada, on the other hand, takes out only 1.5 times as many patents abroad as at home, and the largest portion of its foreign patenting activity occurs in the United States.

Canada's Relative Position as a Source of Technology

The technology which Canada needs to maintain international competitiveness must be created domestically or purchased abroad. It is important, therefore, to examine Canada's position as a producer of technology compared to that of other countries that could be alternate suppliers.

Earlier sections have used data on world patent activity published by the World Intellectual Property Organization (WIPO). This section and those that follow focus on information drawn solely from the records of the Canadian Patent Office. This focus does not, however, eliminate the ability to comment on international as well as Canadian trends in technology generation. Canada, as a member of the Paris Convention, grants patents to foreign nationals under the same criteria as it grants patents to Canadian nationals. Because of the wealth of Canadian society and the diversity of its resources and industrial sectors, Canada is a popular country for the patenting of foreign inventions. Almost 95 percent of 22,797 Canadian patents granted in 1982 covered foreign-origin inventions. Examination of data drawn from the records of the Canadian Patent Office, therefore, provides substantial information on technology of foreign as well as Canadian origin. While the data do give a good picture of foreign inventive activity, it should be borne in mind that they also tend to paint the best possible picture of Canadian and, to a lesser extent, American patenting levels.

National Emphasis

The technological output of the developed countries is by no means homogeneous. Most countries specialize very definitely in one or two particular branches of technology. In some countries these specializations and the general mix of technological output remain relatively constant for long periods, while in other countries, the mix of technological output changes dramatically with time. The technological output mix of ten countries at two points in time is detailed in Table 2-12.

First, looking at the 1983 mix of outputs, it is evident that all countries specialize in one or two branches of technology. Canada, for example, concentrates heavily in mechanical technologies, to the point where output of chemical and electrical technologies is below average. The profile of Swedish output is very similar. Other countries, such as West Germany, specialize very heavily in chemicals, while Japan and the Netherlands show a much higher concentration in electrical patents than the group as a whole.

Turning to the temporal aspect, some countries, such as Canada, the United Kingdom and the United States, have remained relatively constant in terms of the broad composition of technological output over the

TABLE 2-12 Distribution of Canadian Patents by Country of Inventor Across Chemical, Mechanical and Electrical Classes

Country of Inventor	Chemical		Mechanical		Electrical	
	1970	1983	1970	1983	1970	1983
			(percent)			
Canada	23.3	23.4	56.0	57.6	19.1	19.0
France	43.0	43.4	40.0	32.8	16.3	23.8
West Germany	65.1	56.7	24.1	29.0	10.0	14.2
Italy	56.6	44.7	31.6	43.0	11.5	12.2
Japan	58.9	43.2	20.1	26.6	19.5	30.1
Netherlands	37.7	36.1	24.5	22.8	34.7	41.1
Sweden	23.2	25.5	54.5	59.7	19.3	14.8
Switzerland	59.0	48.9	30.5	41.2	9.3	9.8
United Kingdom	43.3	45.0	37.3	37.2	18.7	17.7
United States	36.0	34.3	41.0	41.9	21.3	23.7
Other	37.2	38.7	50.5	48.3	11.0	12.9
Weighted Average	39.5	37.9	40.0	40.0	19.4	22.1

Source: Canadian Patent Office.

14-year time period. Other countries, however, have changed the composition of output markedly. West Germany, Italy and Japan, for example, although still specializing in chemicals technology, all lowered their chemical concentration considerably over that period and added strength in mechanical and electrical fields. France and the Netherlands have both increased concentration in mechanical technologies, while Sweden has increased mechanical concentration at the expense of electrical.

Relative Position

Perhaps more important than the distribution of national outputs across types of technology is the distribution of national outputs within types of technology. It is this latter distribution which determines the relative shares of each country as a generator of each type of technology. These shares have changed substantially over the last 14 years, as shown in Table 2-13, which details for two points in time the distribution of national inventive outputs within the chemical, electrical and mechanical groupings.

The United States dominates in all three categories in both 1970 and 1983. There are, however, some important changes. The U.S. share of output falls markedly in all three types of technology over the time span, particularly in the electrical field. Here much of the American loss in market share has been taken up by rapid growth in the Japanese share.

A large number of countries increased their share of the output of all three types of technology. Canada, for example, registered solid gains in all three categories, as did France and West Germany. More modest gains were registered across the board by Italy and the Netherlands. The United Kingdom and the United States are the only countries to lose presence in all three technologies. The strongest performance is clearly registered by Japan, which more than doubled its 1970 output share in all instances.

The general picture, therefore, is favourable to Canadian interests. As a supplier of technology, Canada has increased its position in the world market in all three categories. Canada's output share remains low, however, which indicates that much of the technology needed by this country must be imported from abroad. Although the United States continues to dominate in all three technology categories, that dominance is lessening as West Germany and Japan become suppliers of note in particular areas. Increasing alternate sources of supply should benefit Canada as a net importer of technology.

Active and Stagnant Technologies

The degree to which the identity of leading-edge technologies changes over time is an important factor in policy formulation. In particular, if the

TABLE 2-13 Distribution of Canadian Patents by Country of Inventor Within Chemical, Mechanical and Electrical Classes

Country of Inventor	Chemical		Mechanical		Electrical	
	1970	1983	1970	1983	1970	1983
			(percent)			
Canada	2.8	3.9	6.8	9.2	4.7	5.5
France	3.6	5.5	3.3	3.9	2.8	5.1
West Germany	11.3	12.7	4.2	6.2	3.6	5.5
Italy	1.5	1.7	0.8	1.6	0.6	0.8
Japan	4.8	10.5	1.6	6.1	3.2	12.5
Netherlands	1.6	2.2	1.1	1.3	3.0	4.2
Sweden	0.9	1.2	2.0	2.8	1.5	1.2
Switzerland	3.5	3.0	1.8	2.4	1.1	1.0
United Kingdom	7.3	2.2	6.3	4.4	6.5	3.8
United States	58.6	47.9	66.6	55.4	70.6	56.9
Other	4.1	5.6	5.6	6.6	2.5	3.2
Total Percent	100.0	100.0	100.0	100.0	100.0	100.0

Source: Canadian Patent Office.

identity of leading-edge technologies changes rapidly and often, it is difficult for policy makers to anticipate, and hence to plan, which fields of technology will be most active over even the medium term.

Use of Canadian patent data permits much greater depth and precision than is possible with the more generalized information collected by WIPO. For the purposes of this study, for example, a special data base was constructed by the Canadian Patent Office detailing by year the number of Canadian patents granted to nationals of each country (Canadian and foreign) in each of over 350 patent classes for the period 1970–83. The patent class system is a very disaggregated classification scheme used by patent examiners and classifiers in searching prior patents to determine if a new application is truly novel. The patent classification systems bears no relationship to the Standard Industrial Class (SIC) system, but is instead designed specifically for disaggregating technological, as opposed to industrial, activity.

Active and Stagnant Technologies Defined

These detailed data were analyzed to determine which of the patent classes were active, neutral or stagnant in the technological output of all nations combined. Because the data are based on patents granted rather than patents applied for, any identification of active, neutral or stagnant technologies may be inadvertently distorted by the sheer administrative machinery of the patent-granting process. In order to eliminate any administrative year-to-year fluctuations, the 1970–83 data were converted to three-year moving averages, reducing the number of observations from fourteen to twelve.

A major part of the analysis which follows depends on the identification of active, stagnant and neutral technologies in terms of patent class activity. In general, an active patent class is defined as one in which the three-year moving average of number of patents granted increases for at least four consecutive observations. Algebraically, therefore, an active patent class ending in period t is defined as:

$$\sum_{K=O}^{2} P_{t-k} > \sum_{K=O}^{2} P_{t-k-1} > \sum_{K=O}^{2} P_{t-k-2} > \sum_{K=O}^{2} P_{t-k-3}$$

where P_{t-k} is the number of new patents granted in year $t - k$. Similarly, a stagnant patent class ending in period t is defined as:

$$\sum_{K=O}^{2} P_{t-k} < \sum_{K=O}^{2} P_{t-k-1} < \sum_{K=O}^{2} P_{t-k-2} < \sum_{K=O}^{2} P_{t-k-3}$$

The residual, that is those patent classes which do not fall into the definition of active or stagnant patent classes, are regarded as neutral.

Stability Measure

To return to the central question of stability over time, active, stagnant and neutral classes were identified for two time periods, the first ending in 1977 and the second in 1983, the last year for which data are available. If, in fact, the identification of leading-edge technologies is relatively stable, one would expect to find that many classes which were active in 1977 would still be active in 1983, particularly given the fairly short time period between the two dates. Table 2-14 shows the number of patent classes which remained constant or changed between the two periods, detailed by active, stagnant and neutral classes.

TABLE 2-14 Changes in Active, Neutral and Stagnant Patent Classes (number of patent classes)

	1983 Active	1983 Neutral	1983 Stagnant	Totals
1977 Active	7	22	11	40
1977 Neutral	20	115	66	201
1977 Stagnant	13	61	48	122
Totals	40	198	125	363

Source: Canadian Patent Office.

Looking first at the "totals" column and row, it is notable that the distribution of classes among active, neutral and stagnant is relatively constant over the time period. This is perhaps surprising, given the overall fall-off in world patent activity after 1972.

While the overall distribution of active, neutral and stagnant classes has remained fairly constant, the identity of particular active, neutral and stagnant classes has changed rapidly and often. Of 40 patent classes which were active in 1977, only seven were still active in 1983 while an even larger number, eleven, had actually become stagnant during the intervening period. Picking winners on the basis of 1977 active classes, therefore, would appear to be a risky task. Picking losers may, however, meet with more success, as almost 40 percent (48 classes) of the 122 classes defined as stagnant in 1977 were still stagnant in 1983.

An overall measure of stability in the identity of active, neutral and stagnant classes is provided (in set theory notation) by:

$$\frac{(A_{77} \quad \Omega \quad A_{83} \quad + \quad N_{77} \quad \Omega \quad N_{83} + S_{77} \quad \Omega \quad S_{83})}{T}$$

where A_{77} is the number of active classes in 1977 and T is the total number of classes. The closer this measure comes to unity, the more stable are the identities of active, stagnant and neutral classes. In the present instance the overall stability index is 0.46, meaning that slightly less than half of the patent classes maintained their 1977 identities through 1983.

It is possible to disaggregate further by providing separate results for chemical, electrical and mechanical classes as distinct groups. In Table 2-15, the overall active stability index is the proportion of patent classes active in 1977 which were still active in 1983. In set theory notation this becomes:

$$\frac{A_{77} \quad \Omega \quad A_{83}}{A_{77}} = 0.17,$$

where A_{77} is the number of active patent classes in 1977. Similarly, the active stability index for electrical classes is given by:

$$\frac{AE_{77} \quad \Omega \quad AE_{83}}{AE_{77}} = 0.30,$$

where AE_{77} is the number of active patent classes in 1977. In general, the higher the index, the greater the probability that an active class in 1977 will be an active class in 1983, and so on.

TABLE 2-15 Stability Indices 1977 to 1983

	Type of Technology			
Type of Class	**Chemical**	**Mechanical**	**Electrical**	**Overall**
Active	0	.08	.30	.17
Neutral	.67	.52	.67	.57
Stagnant	.18	.35	.20	.39
Overall	.47	.43	.45	.46

Source: Canadian Patent Office.

Table 2-15 reveals that in general the identity of active classes is by far the most volatile and that within active classes only the electrical group shows any appreciable stability. By far the most stable situation exists for neutral classes and a fair amount of stability is evident for stagnant classes in the mechanical group. It must be noted that picking 1983 active or stagnant classes on the basis of 1977 active and stagnant classes would lead to failure in well over half the instances. Picking neutral classes, for what it is worth, would be more successful. Overall, there is very little difference in stability between types of technology, whereas there are large differences in stability between active, neutral and stagnant classes.

In general, therefore, it must be concluded that there is a high probability that patent classes which were active in 1977 will be stagnant by 1983 and vice versa. This conclusion holds irrespective of type of technology.

Performance in Active Technologies

Given the high rate of turnover in the identity of active and stagnant technologies, as demonstrated in the last section, considerable flexibility is required of Canadian technology-producing institutions if Canada is to be successful in focussing its efforts on leading-edge technologies. This section explores Canada's performance in active technologies and compares it with the performance of other countries.

Relative Position in Active Technologies

Ideally, each country would like to occupy a strong position as a producer of active technologies. In particular, if a country's position with respect to active technologies is stronger than its position with respect to all technologies, technology generation is well focussed on new growth areas. Table 2-16 details Canada's position in active classes and all classes, and compares it to the position of other countries.

By and large, the relative positions of individual countries with respect to each other is the same in active classes as it is in all classes. In particular, the United States continues to dominate in all three areas while West Germany and Japan turn in strong performances in their particular specialties. There are, however, some interesting results in terms of how well technological output is focussed on active classes.

Canada, for example, exhibits a better position in active classes than in all classes, in chemical and electrical technologies. This is not true, however, for mechanical technologies, where Canada's performance does not appear to be well focussed on the active technologies. This poor record in active mechanical classes gives Canada the greatest negative difference between overall representation in active classes and overall representation in all classes.

It is noteworthy, however, that in all three groupings none of the countries studied is successful in achieving greater representation in active classes than in all classes. The two strongest overall performers in terms of the difference between representation in active classes and representation in all classes are the United States and Japan. The United States appears to be particularly well focussed in chemical and electrical technologies but not in mechanical technologies. Japan, perhaps surprisingly, is not well focussed on active electrical technologies. The position of West Germany is also notable because of an apparent failure to focus on active technologies in both the chemical and electrical areas.

TABLE 2-16 Distribution of 1983 Canadian Patents by Country of Inventor Within Active Classes and All Classes Within Major Groupings

	Chemical		Mechanical		Electrical		Overall		
Country of Inventor	Active Classes Only	All Classes	Active Classes Only	All Classes	Active Classes Only	All Classes	Active Classes Only	All Classes	Differences
					(percent)				
Canada	4.4	3.9	7.3	9.2	5.6	5.5	5.2	6.4	−1.2
France	5.7	5.5	3.3	3.9	5.0	5.1	5.2	4.8	+0.4
West Germany	9.9	12.7	9.0	6.2	3.9	5.5	7.1	8.5	−0.6
Italy	1.7	1.7	1.7	1.6	0.8	0.8	1.3	1.5	−0.2
Japan	11.6	10.5	6.3	6.1	11.9	12.5	11.3	9.1	+2.1
Netherlands	2.5	2.2	0.7	1.3	4.2	4.2	3.2	2.3	+0.9
Sweden	0.9	1.2	4.0	2.8	1.3	1.2	1.3	1.9	−0.6
Switzerland	2.4	3.0	4.0	2.4	1.0	1.0	1.9	2.4	−0.5
United Kingdom	4.6	2.2	3.6	4.4	3.4	3.8	4.0	4.7	−0.7
United States	51.3	47.9	55.2	55.4	59.4	56.9	55.4	52.9	+2.5
Other	5.0	5.6	5.0	6.6	3.3	3.2	4.2	5.5	−1.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	

Source: Canadian Patent Office.

It will be noted that it is often in areas of national specialization (Canada in mechanical, Japan in electrical, and West Germany in chemical, for example) that countries appear to have difficulty focussing on active classes.

Response to Change

Related to current relative position in active classes is the issue of whether national technology-producing institutions are responsive to change. It has already been noted that the identity of active and stagnant classes changes often and rapidly, and hence a high degree of flexibility is required to move inventive resources out of stagnant areas and into active areas. In Table 2-17, the percentage-change figure given is the difference between the number of Canadian patents granted in those classes for 1977–79 and for 1981–83. A priori, it is expected that a country that is responsive to international trends will show a negative percentage change for stagnant classes and a positive percentage change for active classes. Several other measures, including average annual growth rates, were explored for this analysis but were not used due to a high variation in year-to-year patenting activity.

The overall impression gained from examination of Table 2-17 is that with a few exceptions, all of the signs meet a priori expectations. This in itself is somewhat surprising. The United States, for example, is a technology trend-setter in the current data context, as it is the origin of over 50 percent of Canadian patents in most classes. The United States would therefore be expected to register the expected signs. It is surprising, however, that all countries seem to be part of the technological trends, as if promising avenues of invention are identified by implicit consensus.

There are, of course, exceptions. The United Kingdom in particular seems to be unresponsive, not increasing technological output in active classes in the mechanical and chemical fields and registering only a small increase in the electrical field. Canada's performance in all sectors registers the correct signs in a strong fashion.

Table 2-17 also permits comparison of national results with those of the group as a whole. Looking at Canada, for example, performance in moving into active classes is weaker than the mean in both mechanical and chemical groups. Canadian performance in moving out of stagnant areas is, however, stronger than that of the group in both electrical and chemical technologies. The result is that Canadian response to change is particularly strong in the electrical field, particularly weak in the mechanical field, and mixed for chemical technologies. Given Canada's heavy relative emphasis on mechanical technologies, overall response to change is weaker than the mean in both active and stagnant classes.

TABLE 2-17 Percentage Change Between 1977–79 Total Canadian Patents and 1981–83 Total Canadian Patents by Country of Inventor for Indicated Active and Stagnant Classes

	Chemical		Mechanical		Electrical		Overall		
Country of Inventor	Active	Stagnant	Active	Stagnant	Active	Stagnant	Active	Stagnant	Differences
Canada	14.4	−16.8	37.7	−22.8	42.2	−68.7	29.4	−23.9	53.3
France	31.4	−2.0	85.7	−28.0	83.5	12.5	51.0	−22.9	73.9
West Germany	4.7	−18.9	49.1	−23.4	37.9	−20.0	15.1	−22.0	37.1
Italy	0.8	−47.5	133.3	−36.7	67.7	a	21.6	−37.2	58.8
Japan	59.8	−22.7	2.7	−25.8	59.7	−32.0	57.1	−25.4	82.5
Netherlands	38.6	3.2	−14.3	−24.7	21.5	−28.1	27.2	−21.5	48.7
Sweden	0	−25.0	0	−34.7	121.2	a	42.1	−33.9	76.0
Switzerland	67.6	−9.0	150.0	−27.9	6.0	a	49.2	−25.2	74.4
United Kingdom	−0.3	−17.9	−8.0	−43.2	4.0	−21.6	0.9	−38.3	39.2
United States	30.9	−5.4	45.0	−38.9	32.0	−30.7	32.4	−33.5	65.9
Weighted Average	26.7	−10.9	41.1	−35.2	36.3	−30.6	32.0	−31.0	63.0

Source: Canadian Patent Office.

a. Number of patents too small to provide reportable results.

These results must, however, be taken in context, as there is no one country which exhibits stronger than average response for active and stagnant technologies right across the board. France, for example, has one of the strongest responses in terms of moving into active classes yet also registers one of the weakest responses in terms of moving out of stagnant areas.

In terms of overall response in increasing activity in active classes, Japan is a clear leader, followed by France, Switzerland and Sweden. Canada ranks sixth, just behind the United States, in moving aggressively into expanding areas. In terms of moving out of areas of decreasing activity, there is very little difference in national response rates, indicating that all nations are quick to identify areas of diminishing returns.

Summary and Conclusions

This paper has focussed on providing information on a number of very distinct issues concerning technology generation in Canada and abroad. In the process, large amounts of data from the Canadian Patent Office and the World Intellectual Property Organization have been reviewed and a number of conclusions have been drawn. The purpose of this section is to draw together the main results and conclusions and to interpret them in the context of some of the current issues in technology policy.

The conclusions should be viewed against a background of considerable, and often surprising, international change in rates of technology generation and diffusion. Contrary to popular perception, new technology has not been invented at an ever faster rate in recent decades. Rates of invention reached their highest level in 1972 at 136 percent of their 1930 figure and had fallen back to 116 percent of that total by 1982. On the other hand, the rate of technology diffusion internationally accounted for two-thirds of the worldwide growth in patenting since the interwar period and diffusion rates fell faster than rates of invention in the economically troubled 1970s.

Canada, it seems, fares reasonably well in world terms as a recipient of new technology. This country grants the third highest number of patents to foreign nationals, after the United States and Britain. While a high proportion of these come from the United States, Canada still ranks fourth in the world as a recipient of non–U.S. patents, and the U.S. portion has been falling in recent years. The high numbers are undoubtedly due in part to the fact that Canada is potentially able to exploit a broad range of new technologies for the large U.S. market. In other words, some portion of foreign patenting in Canada may be insurance against Canadian rivalry. Nevertheless, the result is that each year Canada receives a large flow of detailed information on new technolo-

gies, which has the potential for use under licence by Canadian industry. The fact that much of this information is not readily available to other countries can only provide Canada with an advantage as a potential user.

As a source of new technology, Canada remains a small player, creating only 0.3 percent of the world's patented inventions compared to Japan at 9.9 percent, the United States at 8.0 percent, Germany at 1.9 percent and France at 1.8 percent. Canada's relatively small economy is not sufficient to explain this, since Canadian domestic patenting rates appear comparatively low even when indexed to GNP. However, Canada has fared better than most in maintaining its world share of technology generation. Canada's share remained stable throughout the 1970s and early 1980s, while the shares of the other countries have been reduced by varying amounts. (Japan is the exception here, with a steadily increasing share.)

Canada has, however, been unimpressive as an exploiter of its technology in other countries. Residents of countries other than the United States and Japan with disproportionately large rates of domestic patenting tend to take out many more patents abroad than they do at home. This is not the case with Canada, whose residents are granted only 1.5 times the number of patents abroad as at home, compared with 4.2 for Germany, 2.2 for the United Kingdom, and 9.9 for the Netherlands. The reasons for Canada's low propensity to patent abroad would seem to be an important area for further study, as a prelude to encouragement of better international exploitation of Canadian technology.

A continuing technology debate in Canada and abroad concerns the advisability of picking winners and losers for R&D support. One faction would prefer to see the government pick winning and losing technologies and provide funding and support accordingly. The other faction maintains that the private market does an adequate job of responding to change and that picking winners and losers is almost impossible for government in any case.

The data and analysis contained in this paper tend to support the position that governments should be very cautious in becoming involved in selective support policies. Firstly, it has been demonstrated that the identity of both active and stagnant technologies changes often and quickly. Specifically, a winner (active class) picked on the basis of 1977 patent information had only a 17.5 percent chance of still being a winner in 1983. There was actually a higher probability (27.5 percent) that the winner would have become a loser (stagnant class) by 1983. The probability of successfully picking losers is somewhat higher (40 percent) but still not satisfactory.

While the high turnover in the identity of active classes makes selective government support difficult, this is not really an issue which should be of great concern to policy makers. The data also show that the individual national players in the technology market are already

responding very well to change. This result holds true for all the nations studied, which implies that there exists a network of private signals which leads technology generators to an implicit consensus concerning emerging opportunities. In particular, all nations have been quick to move out of stagnant areas and most have been quick to move into active areas. Canadian response to change has been consistently in the right direction, although response in the electrical field was stronger and response in the mechanical field was weaker than the group mean. The overall message, therefore, is that the current market mechanism for responding to emerging changes in active and stagnant technologies appears to work well for all nations, including Canada. Indeed, Canada holds a better share of the market in active electrical and chemical classes than it does in electrical and chemical classes in general. Any potential benefits from selective government actions must therefore be considered marginal, at least in these areas.

Another continuing technology debate concerns the relative emphasis on domestic generation of technology versus purchase of technology or capital-embodied technology from abroad. Clearly, not all technology can be created domestically, and the data would lead one to conclude that only a small proportion of the technology needed in Canada is produced in this country. A large part of Canada's technological needs therefore must be met by purchases or licences from abroad. The data show that sources of supply in the international technology market appear to be becoming more diversified. While the United States continues to dominate technology in all areas, that dominance is lessening. At the same time, other nations, particularly Japan and West Germany, have carved out niches in particular fields as a result of concentrating inventive efforts on particular areas of technology. This is true of Japan in chemical technology. Moreover, these market niches are generally as strong in active technologies as they are for all technologies.

The growth of alternate sources of supply is welcome news for Canada, since it is a net purchaser of technology. What remains is to develop policies and programs to take advantage of the growth of the alternative sources by providing Canadian purchasers with information which facilitates the identification of competing suppliers and technological options.

This paper has not commented on many of the important issues surrounding technology application, but has provided information on international activity in technology generation. In particular, while the pace of technology application may be increasing, the pace of technology creation has actually declined since 1972. Despite this overall decline, Canada has maintained its output and Japan has increased output markedly. Canada, overall, responds well to changes in active and stagnant technologies. This response, which extends across all countries, is much better than expected. Governments should therefore

be cautious about using selective policy levers to create domestic technology, but they do have an opportunity to be proactive in encouraging the purchase of technology from a more diversified international market.

Notes

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1. For detailed criticisms, see Lawson and Holman (1980) and Pavitt (1982).
2. Since levels of patent exploitation cannot be easily determined, this assumption is open to some criticism. It is made on the grounds that patentees go to the trouble and expense of patenting abroad when the importance of an invention and the likely commercial return are sufficiently great. The validity of the assumption would seem to be supported by the strong statistical correlation established by Pavitt (1982), between patenting abroad and domestic R&D levels.
3. GNP figures at 1980 prices derived from *International Financial Statistics Yearbook* (Washington, D.C.: International Monetary Fund, 1983).

Bibliography

International Monetary Fund. *International Financial Statistics*. Washington, D.C. (published monthly).

Lawson, W.S., and M.A. Holman. 1980. "Patent Statistics as Indicators of Technological Output." Organisation for Economic Co-operation and Development, Science and Technology Indicators Conferences, September. Paris: OECD.

Pavitt, K. 1982. "R and D, Patenting and Innovative Activities." *Research Policy* 11.

World Intellectual Property Organization (WIPO). 1983. *100 Years of Industrial Property Statistics*. Geneva.

3

Technological Change and the International Diffusion of Technology
A Survey of Findings

EDWIN MANSFIELD

Although much has been written about technological change and the international diffusion of technology, many knotty and persistent problems remain in measuring the relevant variables and obtaining the proper data. The Royal Commission on the Economic Union and Development Prospects for Canada posed the following questions designed to elicit an adequate and fair summary of the current state of economic knowledge in this area.

- Does there seem to have been an acceleration in the rate of technological change?
- From what countries do innovations appear to be emanating, and how has this changed over time?
- At what rate do new technologies spread domestically and internationally and has the rate of diffusion increased?
- What sorts of countries tend to be relatively quick to get new technologies? What sorts tend to be relatively slow?
- What is the role of multinational firms in transferring technology across national lines? Is there now more of a tendency to transfer technology by arm's-length means?
- Is there an increasing tendency to decentralize research and development (R&D) internationally? If so, what types of R&D are done abroad and in what kinds of countries?
- Does Canada have any prospect of increasing its share of the R&D effort of multinational firms?
- Is there any evidence that a small country can intervene successfully in the technology process to increase the pace of receiving new technologies (and the flexibility of their use) and to reduce their cost?

This paper surveys the available evidence relating to these eight questions. They are difficult questions to answer in other than a tentative and incomplete fashion. The limitations of the available evidence should be recognized at the outset. In addition, space limitations require a selective review of the literature and a very judicious pruning of the material to be included in the bibliography.

The Pace of Technological Change

Society's pool of technological knowledge has had an enormous impact on the industrial and medical arts. Because technological change represents advances in knowledge, it is notoriously difficult to measure. Nonetheless, in the face of pressing questions by policy makers and others, scholars have done what they could to construct measures of the rate of technological change.

There have been spectacular advances in recent years in such areas as information technology and microelectronics. For example, the cost of computer main memory has been falling by more that 20 percent a year since 1965, and this decline is expected to continue throughout the 1980s. Microprocessors are being used more and more to control industrial processes. Financial institutions are using electronic fund transfer systems and automated methods of handling paper-based transactions. Word processors and other types of equipment are penetrating the office. Pocket calculators, electronic watches, and personal computers have entered the home.

Another area where progress has been particularly rapid is biotechnology, with wide potential applications in many aspects of medical and chemical practice. Relevant techniques involve the employment of restriction enzymes to isolate and remove gene sequences from DNA molecules and recombine them with the DNA of other organisms. The application of methods to reproduce large amounts of exact copies (clones) of the hybrid or recombinant DNA molecules has also been involved. Work is going on to develop new types of plants and modify the genetics of animals. The potential effects on the economy are substantial.

However, information technology, microelectronics, and biotechnology are not typical areas of technology. If one looks at the entire range of technology, there is some evidence that the rate of technological innovation may have slowed during the 1970s and early 1980s, as did U.S. productivity during this period. Of course, the fact that there was a productivity slowdown does not prove by itself that there was a slowdown in the rate of innovation, but many experts such as Kendrick (1980) believe that the productivity slowdown was due in part to a reduction in the rate of innovation.

Patent statistics are another kind of relevant evidence. As shown in Mansfield et al. (1982), the patent rate in the United States has been falling since about 1969. In practically all of the 52 product fields for which data are available, the number of patents granted annually (by year of application) to U.S. inventors declined during the 1970s. However, the crudeness of patent statistics as a measure of the rate of invention should be emphasized. The average importance of the patents granted at one time and place may differ from those granted at another time and place. The proportion of total inventions that are patented may vary substantially. Nonetheless, for what it is worth, there has been a decline in the patent rate in many countries, such as Germany, France, and Britain, as well as the United States, and this often is regarded as evidence of a decline in the rate of invention.

In such industries as pharmaceuticals and agricultural chemicals, there is direct evidence of a fall in the rate of innovation. For example, in the pharmaceutical industry, the number of new chemical entities introduced each year in the United States declined relative to the number reported during the 1950s and early 1960s. This measure suffers from the fact that it is difficult to find suitable weights to distinguish among different innovations. Also, this measure overlooks the small innovations that sometimes have a bigger cumulative effect than some of the more spectacular innovations. Nonetheless, measures of this sort have frequently been used and are of interest. In Canada, De Melto, McMullen and Wills (1980), for example, find that the median expenditure per innovation declined during 1965–79.

Although it would be foolhardy to consider the above data as reasonably reliable indicators of the rate of technolgical change, it may well be that there was some fall in the rate of technological change in such sectors as pharmaceuticals and agricultural chemicals. There are a number of reasons why such a slowdown might have been expected. According to many studies, the rate of technological change (as measured by shifts in the production function) is directly related to the rate of increase of R&D "capital," defined as the sum of previous (depreciated) R&D expenditures. Total R&D expenditures in the United States between 1967 and 1977, adjusted for inflation, seemed to remain essentially constant. This reduction in the rate of growth of R&D expenditures, which was due partly to a cut in government-financed R&D and partly to slower growth in industry spending on R&D, could be expected to result in a reduction in the rate of technological change.

Besides the fall in the rate of growth of R&D "capital," there was also a shift away from more basic, long-term, and risky R&D in many industries, such as aerospace, chemicals, and rubber. This change in the composition of R&D may also have tended to depress the rate of technological change. According to executives responsible for R&D pro-

grams, increased government regulations (which in their opinion reduced the profitability of relatively fundamental and risky projects) as well as the high inflation rates of the 1970s in part brought on this shift in the composition of R&D in these industries (Mansfield, 1980).

In the past year or so, there has been a feeling among academic and industry observers that an increase in the rate of technological change may be underway. R&D spending by U.S. industry increased much more rapidly in real terms during 1975–83 than during 1968–75. A revival in the rate of productivity increase is being predicted by Kendrick and others.[1] However, as emphasized above, measures of this sort are very imperfect. Although there are some signs of an increase in the rate of technological change, it is too early to tell whether these signs are really trustworthy or not.

Sources of New Technologies

The Organisation for Economic Co-operation and Development (OECD, 1970), as part of its study of the technology gap, presented data in 1970 concerning the country where each of 110 significant post-1945 innovations was first exploited commercially. The United States accounted for 67 percent of these, Britain for 16 percent, Germany for 13 percent, and Japan for 4 percent. A National Science Foundation study (1975) of the sources of 492 technological innovations, like the OECD study, indicated that the bulk of the innovations originated in the United States, but there was an indication that the U.S. share of the total was falling. Whereas the United States accounted for about 80 percent of innovations introduced during the 1953–58 period, the proportion fell to 67 percent during 1959–64, and to 57 percent during 1965–73. At the same time, Japan's share increased from zero during 1953–58 to about 10 percent during 1965–73.

Although research and development is an input, not an output, the relative size of the industrial R&D expenditures of various countries provides useful information concerning the source of technologies. The United States in 1975 accounted for about 50 percent of all industrial R&D expenditure among OECD countries. Germany and Japan each accounted for about 12 percent, while France and Britain each accounted for 6 or 7 percent (OECD, 1979). Total R&D expenditures in 1979 amounted to about $55 billion in the United States, $21 billion in Germany, $19 billion in Japan, $11 billion in France, and $7 billion in Britain (National Science Foundation, 1983a).

A limited amount of survey data has been obtained concerning the perception of technology gaps. In particular, a survey by Mansfield (1984a) asked the leading executives of 100 major American firms to rank the level of technology in 1983 among counterparts in each of the five largest industrialized, non-Communist countries — France, Germany,

Japan, Britain and the United States. Each firm was chosen at random from a comprehensive list of firms in 13 major manufacturing industries. The results are obviously very rough, but it is clear that in a much wider range of industries than is commonly supposed, Japan is perceived to be the principal technological rival of the United States.

In pharmaceuticals, machinery, instruments, and rubber, as well as in the more familiar cases of primary metals, electrical equipment, and transportation equipment (principally motor vehicles and related items in this sample), Japan seems to have forged ahead of France, Germany, and Britain. In chemicals, where Germany has long had great technological strength, it is noteworthy that Japan is considered to have almost achieved parity with Germany. Only in the petroleum, glass and "other" industries[2] is Japan ranked appreciably below Germany. Of course, the executives' evaluations of their own country's relative position may be biased. Primary metals is the only industry in which they concede that the United States is not first and in transportation equipment they essentially claim a tie for first.

Besides ranking the five countries according to their technology levels in 1983, the U.S. executives also ranked them by the extent of the improvement in their technology during 1968–83. The results show that in eight of the eleven industries,[3] Japan was regarded as having achieved the highest rate of technological advance. Only in petroleum, glass, and "other" industries was Japan other than first. Thus, if there was a bias favouring the United States, Japan's performance was impressive enough to have more than offset it. The United States and Germany were often ranked second and third, with France and Britain bringing up the rear in practically all cases.

Still another kind of data that is relevant here pertains to the nationality of inventors granted patents in the United States. As shown in Table 3-1, the percentage of U.S. patents granted to Americans declined from 80 percent in 1966 to about 60 percent in 1982. The Japanese percentage increased greatly — from 1.6 percent in 1966 to 14.1 percent in 1982 — and the German percentage has increased from 5.8 percent to 9.3 percent. Although these data reflect many factors besides the relative inventiveness of various countries, they certainly are consistent with a decrease in America's share of world inventions and an increase in Japan's and Germany's shares.

Turning to Canada, 1960–79 data compiled by De Melto, McMullen and Wills (1980) for 122 Canadian innovations that were imitations of foreign innovations show that 64 percent were from the United States, 7 percent from Germany, 4 percent from Japan, 4 percent from France, and 2 percent from Britain. The U.S. share recorded here is somewhat higher than that found in a previously cited study by the National Science Foundation (1975), which suggests that the United States may be more important as a source for technology transfer to Canada than as

TABLE 3-1 U.S. Patents Granted to Inventors from Selected Countries, 1966 and 1982

Country	1966	1982
United States	54,634	33,896
Germany	3,981	5,409
Japan	1,122	8,149
United Kingdom	2,674	2,134
France	1,435	1,975
Switzerland	983	1,147
Canada	938	990
USSR	66	209
Other EEC countries	782	1,014
Total	68,405	57,887

Source: National Science Foundation, *Science Indicators, 1982* (Washington, D.C.: U.S. Government Printing Office, 1983).

a source for all major innovations. On the other hand, Japan and Britain seem to be somewhat less important as sources of such technology transfer to Canada than as sources for all major innovations.

In the study by De Melto, McMullen and Wills (1980) of 283 major Canadian innovations, there were 82 cases where the primary technology for the innovation was wholly or partly acquired from outside Canada. The United States was the source for 77 percent of these cases, Britain for 5 percent, Germany for 4 percent, and France for 2 percent. Even for innovations of this sort by Canadian-controlled firms (16 of the 82 cases), the United States was the source for 63 percent of the cases, Britain for 6 percent, and Germany for 12 percent. Thus, it appears that the United States may be somewhat more important as a source of technology transfer to Canada than as a source for all major innovations. This result, which echoes that in the previous paragraph, seems reasonable, given the major role of U.S. multinational firms in Canadian manufacturing.

International Diffusion of New Technologies

Studies of industries such as synthetic materials and semiconductors indicate that countries differ considerably in how rapidly they begin using a new process or producing a new product. The speed with which a country begins producing a new product could be expected to be directly related to how much the country spends on research and development in the relevant industry. Countries that spend relatively large amounts on R&D in the relevant industry are likely to be close to the technological frontiers and able to imitate quickly, whereas other countries may not be able to do so.

Also, there is likely to be a tendency for imitation rates to be faster for more recent innovations than for earlier ones. Because of improvements in communications, transportation, and methods for evaluating investments in facilities to produce new products, one might expect such a trend toward higher international diffusion rates. Furthermore, how rapidly a country begins producing a new product may be affected by the level of concentration in the relevant industry in this country. In some industries, decreases in concentration may mean more rapid imitation because of greater competition. In other industries, decreases in concentration may mean less rapid imitation because the industry may be too fragmented to allow any member to amass the necessary resources quickly.

Data published by Mansfield et al. (1982) concerning the diffusion of major innovations in the plastics, semiconductor, and pharmaceutical industries in the five major non-Communist countries tend to bear out these hypotheses. In the plastics and semiconductor industries, there is a highly significant tendency for countries that spend relatively large amounts on R&D to have relatively short imitation lags. On average an increase of 10 percentage points in a country's share of total R&D in the industry is associated with a reduction in the imitation lag of about two or three years. In the pharmaceutical industry, there appears to be no such tendency, perhaps because of regulatory considerations. In all three industries, when other factors are held constant, imitation lags tend to decrease with time. The extent of the decrease seems smallest in semiconductors and greatest in plastics. The effects of industrial concentration on a country's imitation lag appear to be mixed. In pharmaceuticals, increased concentration seems to be associated with longer imitation lags; in plastics, the reverse seems to be true; and in semiconductors, there seems to be no statistically significant relationship between them.

How rapidly a country begins using a new process or producing a new product may depend on how rapidly a multinational firm transfers the technology overseas.[4] Based on data assembled by Mansfield and Romeo (1980) concerning 65 technologies that were transferred overseas by U.S.-based multinational firms during 1960–78, the mean age of the technologies transferred to overseas subsidiaries in developed countries was about six years, which was significantly less than that for a corresponding transfer to developing countries (about ten years). Because many newer technologies are inappropriate for developing countries or are difficult and expensive to transfer there, the technology transferred to developing countries could be expected to be older than that transferred to developed countries. The mean age of the technologies transferred through licences, joint ventures, and other channels besides subsidiaries tends to be higher (about 13 years) than the mean age of the

technologies transferred to subsidiaries. More will be said on this score in the next section.

For technologies transferred to subsidiaries in developed countries, the proportion of transferred technologies that were less than five years old (at the time of transfer) was much greater (75 percent versus 27 percent) in 1969–78 than in 1960–68. But for technologies transferred through channels other than subsidiaries, there appeared to be no such tendency, at least in this sample. Davidson and Harrigan (1977) present valuable evidence concerning the age of technologies transferred abroad by U.S.-based firms, at the time when they were first transferred abroad. Their results suggest, too, that the average age of technology transferred abroad has declined. Based on data for 532 products, they find that the percentage introduced in foreign markets within one year of U.S. introduction rose from 6 percent in 1945–50 to 24 percent in 1961–65 and to 39 percent in 1971–75. Similarly, the percentage introduced in foreign markets within five years of U.S. introduction rose greatly during this period.

There frequently are considerable international differences in the rate of intra-country diffusion of an innovation. Many studies indicate that the diffusion rate depends on the profitability of the innovation. In addition, a variety of other factors can be important, such as the variation among firms in the profitability of the innovation, the size of the investment required to introduce the innovation, the number of firms in the industry, their average size, the inequality in their sizes, and the amount that they spend on research and development. Econometric models have been devised to explain and forecast the rate of diffusion of innovations. Although over-simplified in many respects, these models have provided a surprisingly good fit to data for a wide variety of industries and countries.

Globerman (1975a, 1975b) and Daly and Globerman (1976) conclude that the rate of diffusion of numerically controlled machine tools and of tufting equipment in carpet making has been lower in Canada than in the United States. On the other hand, Baumann (1973) finds that diffusion of the basic oxygen process in steel was more rapid in Canada than in the United States. Clearly, comparisons of this sort will turn up different results, depending on the industry (see Mansfield, 1977). In general, the Economic Council of Canada (1983) seems to conclude that the diffusion process goes on relatively slowly in Canada. If true, this has an important bearing on public policy. More research should be aimed at determining if and why this is true and what should be done about it.

Patterns of International Technology Transfer

As pointed out above, the mean age of the technologies transferred by U.S.-based multinational firms to their overseas subsidiaries tends to be

lower for subsidiaries in developed countries (about six years) than for those in developing countries (about 10 years). De Melto, McMullen and Wills (1980) provide valuable data concerning the lag between the first commercial launch of products or use of processes in the world during the 1960–79 period and the first launch or use in Canada. On average, the lag is about eight years, as shown in Table 3-2.

TABLE 3-2 Lags in the Introduction of Innovations Developed Abroad into Canadian Industry, 1960–79

Industry	Average Number of Years Between First World Launch or Use and First Launch or Use by Reporting Canadian Firm
Product Innovations	
Telecommunications	5.5
Electrical equipment	9.3
Plastics and resins	7.5
Smelting and refining	10.3
Petroleum	5.0
Total	7.4
Process Innovations	
Telecommunications	5.8
Electrical equipment	5.0
Plastics and resins	7.3
Smelting and refining	11.8
Petroleum	7.7
Total	8.7

Source: D. DeMelto, K. McMullen, and R. Wills, "Preliminary Report: Innovation and Technological Change in Five Canadian Industries," Discussion Paper 176 (Ottawa: Economic Council of Canada, 1980), p. 18.

However, this average is based on imitative innovations carried out both by Canadian-controlled firms and foreign-controlled firms. If one considers only those imitative innovations that were transferred within a multinational firm to a Canadian subsidiary, the mean lag is 6.1 years for products and 5.1 years for processes. This is strikingly similar to the figure of 5.8 years for all overseas subsidiaries in developed countries that Mansfield and Romeo (1980) find. Thus, it appears that Canadian subsidiaries of multinational firms receive technology from their parents (or other parts of the enterprise) with about the same lag as other subsidiaries in major developed countries.

Based on data for 733 new products introduced by 44 firms in a variety of manufacturing industries, Davidson and Harrigan (1977) find that the percentage of new products transferred to Canada before any other country declined from 26.2 percent in 1945–55 to 14.4 percent in 1956–65 and to 6.5 percent in 1966–75. On the other hand, the percentage transferred first to developing countries increased from 19.9 percent to

20.3 percent and to 28.8 percent respectively, during the same periods. Apparently, U.S. multinationals have become less likely to transfer innovations first to Canada and more likely to transfer them first to developing countries. Thus, although Canadian subsidiaries seem to receive new technology about as quickly as others in developed countries, they seem to receive it less rapidly relative to other countries (particularly developing countries) than in the past.

Multinational Firms and International Technology Transfer

There are many channels of international technology transfer. One important channel is the export of goods. The mere existence or availability of a good in a foreign country may result in the transfer of technology, since the good may provide information to the importers of the good. Thus, the export of advanced computers to a particular country may result in technology transfer. In addition, the country may gain technology because the exporters of a product will help the country to use it efficiently. For example, it may help train workers. Also, if the country that imports the good is able to take it apart in order to determine how it is made (i.e., reverse-engineer it), there is, of course, the opportunity for more technology transfer.

Another important channel is licensing. A firm with a significant new product or process may engage in licensing agreements with foreigners covering patents, trademarks, technical assistance, and other matters. Licensing agreements often call for the licensee to pay a certain percentage of its sales to the licensor, plus a flat fee for technical help, in some cases. Another channel is the formation of a joint venture, i.e., an operation owned jointly by the firm with the technology and a firm or agency of the host country. Joint venture agreements often are made by smaller firms that need capital to complement their technology.

Still another way of transferring technology is through setting up and using subsidiaries overseas. At this point, multinational firms have in place extensive overseas manufacturing facilities, and they transfer technology by training operatives and managers, communicating information and capabilities to engineers and technicians, helping the users of their products to use them more effectively, and helping suppliers to upgrade their technology. According to the available evidence, firms seem to prefer this channel over licensing if they can obtain the necessary resources and if they fear that licensing will give away valuable know-how to foreign producers who are likely to become competitors in the future.[5]

Of course, the longer the estimated life of the innovation, the less inclined a firm is to enter a licensing agreement. Also, firms prefer direct investment over licensing when the technology is sophisticated and foreigners lack the know-how to assimilate it, or when a firm is con-

cerned about protecting quality standards. On the other hand, licensing is often preferred when the foreign market is too small to warrant direct investment, when the firm lacks the resources for direct investment, or when advantages accrue through cross-licensing.[6]

Some evidence concerning the importance of multinational firms in the process of international technology transfer can be gleaned from U.S. data concerning receipts and payments of royalties and fees (see Kroner, 1980, and National Science Foundation, 1983a). Although these data suffer from many important limitations, they suggest that U.S. receipts and payments of royalties and fees associated with direct investment are far greater than those associated with unaffiliated foreign residents. Specifically, about 80 percent of all U.S. royalty and fee receipts come from U.S. subsidiaries abroad.

A study by De Melto, McMullen and Wills (1980) of 283 major Canadian innovations introduced between 1960 and 1979 shows that 96 of them were based primarily, in whole, or in part on externally controlled technology. As pointed out earlier, in 82 of these cases, the technology was acquired from outside Canada. In 54 percent of the 96 cases, the technology came from another part of a multinational firm of which the innovator was a member. In only 46 percent did the technology come from arm's-length sources, such as suppliers (14 percent), consultants (12 percent), joint ventures (9 percent), and customers (5 percent). According to this same study, the proportion of all reported innovations relying on externally acquired technology declined during the 1970s. Innovations primarily based on imported technology between 1976 and 1979 constituted only 11 percent of the innovations of Canadian-controlled firms and 36 percent of those of foreign-controlled firms.

Most of the technologies transferred in cases where the innovation was foreign-controlled were covered by technology transfer agreements allowing Canadian subsidiaries full access to R&D resources available within the multinational firm. Subsidiaries generally pay an annual fee (not specific to the technology transferred) to the parent company. Eighty percent of these agreements provided for a continuous transfer of technology. As the supplier develops better technologies in the relevant areas, it is made available to the recipient. About two-thirds give rights to sell; about three-quarters give rights to manufacture. About one-third specify the territory of sales (and in over 80 percent of these cases, the firm is confined to selling only in Canada).

The Increased Importance of Arm's-Length Transactions

Many observers believe that there has been an increase in recent years in the extent to which technology is transferred by arm's-length means. Thus, Davidson and Harrigan (1977) report that the percentage of new products transferred to independent licensees increased from 12 percent

during 1961–65 to 21 percent during 1971–75. An empirical study by Telesio (1977) indicates the U.S. firms are increasingly willing to consider licensing as a substitute for direct investment. According to Contractor and Sagafi-Nejad (1981), "Corporate policies which a decade ago would almost reflexively have ruled out anything but equity investment are being reassessed" (p. 119) and corporate licensing departments are being upgraded. In part, this seems to be due to increasingly restrictive government policies regarding direct investment. For example, the Andean Pact, including Latin American countries such as Bolivia, Colombia, Ecuador and Peru, in 1971 introduced "fade-out" rules requiring foreign affiliates to sell shares to local investors and to increase the local content of their products. In a similar vein, Mexico's 1973 law on the transfer of technology requires government approval for all technology agreements with foreign companies.

There are many imperfections in the market for technology licences. Frequently, there are few willing sellers of the technology, and the number of potential (competent) licensees may be small as well. It is very difficult for the potential licensee to evaluate the returns from the technology, and there are many uncertainties. Transaction costs may be high. Nonetheless, according to Caves, Crookell and Killing (1983, p. 265):

> There is every sign that technology licenses and related transactions in intangible assets will become more important in international commerce. Both negative and positive factors support this prediction. Negatively, governments seem increasingly prone to restrict and regulate foreign direct investment and to prefer technology licensing as an alternative to the multinational company. Positively, the creation of new technology is probably both more extensive and more far-flung than ever, and the number of companies capable of participating in the licensing market expands steadily. Despite its limitations, the license market will become more important both in commercial practice and as a concern for public policy.

Baranson (1978, p. xi) believes that U.S. firms have changed their approach to the transfer of technology:

> Under certain circumstances, a growing number of U.S. corporations now find attractive the sale of industrial technology to noncontrolled foreign enterprises. . . . The technology sold in such cases is increasingly the most sophisticated and latest generation available, and its release is often under terms that assure rapid and efficient implantation of an internationally competitive productive capability.

In his view (pp. xi–xii), this change is due to five factors:

> (1) The demands of newly industrialized nations for technology sharing and access to world markets. (2) The intensified political risks and economic uncertainties of overseas capital investments in plant and equipment. (3) The shifting emphasis in certain firms from production to marketing and

> R&D functions. (4) The intensified competition from foreign enterprises as suppliers of industrial technology and the consequent compulsion to release proprietary technology early in the product cycle. (5) The escalation of R&D and capital investment costs connected with the proliferation of world involvements and the ever-increasing sophistication of product systems.

Although it is not clear that multinational firms are a less important source of inventions and innovations than in the past, the substantial restrictions and regulations that make it difficult for such firms to utilize their technology abroad could reduce the incentive for them to carry out R&D. For example, a study of 30 U.S.-based firms by Mansfield, Romeo and Wagner (1979) finds that about 30 percent of their expected returns from R&D projects were expected to come from abroad. If their R&D results could not be exploited through their foreign subsidiaries, the firms estimated that their volume of R&D would drop by 12 to 15 percent.

With regard to Canada, McMullen (1983) counsels caution in the treatment of multinational firms, since her results indicate that they tend to reduce the lags associated with the adoption of products and processes first introduced outside Canada. Caves, Crookell and Killing (1983, pp. 265–66) point out that:

> In general, both the source and the recipient countries lose if technology transfers are diverted toward arm's-length license agreements that would otherwise have occurred through some joint-ownership channel. Some transfers will occur but at greater resource cost. The recipient will accept terms that sometimes impair the revenue productivity of the transferred technology and discourage local research to improve and advance the technology. And some technologies simply will not be transferred, because mutually acceptable agreements cannot be reached.

Overseas R&D of Multinational Firms

Besides setting up production facilities abroad, multinational firms have also established overseas R&D laboratories. As indicated in Table 3-3, the share of R&D expenditures carried out overseas by U.S.-based firms increased during the 1960s and early 1970s, and reached about 8 percent during the mid-1970s. There are many reasons for this increase, including the presence of environmental conditions abroad that cannot easily be matched at home, the desirability of doing R&D aimed at the special design needs of overseas markets, the availability and lower cost of skills and talents that are less readily available or more expensive at home, and the greater opportunity to monitor what is going on in relevant scientific and technical fields abroad. According to a sample of 55 major firms investigated by Mansfield, Romeo and Teece (1979), the principal reason is to respond to special design needs of overseas markets.

TABLE 3-3 **Company-Financed R&D Expenditure Carried Out Overseas, U.S.– Based Firms, 1960–81**

	Percentage[a]
1960	2
1965	6
1970	6
1975	8
1981	8

Source: E. Mansfield, A. Romeo, M. Schwartz, D. Teece, S. Wagner, and P. Brach, *Technology Transfer, Productivity, and Economic Policy* (New York: W.W. Norton, 1982); and National Science Foundation, *Science Indicators, 1982* (Washington, D.C.: U.S. Government Printing Office, 1983).

a. The 1960–70 figures pertain to a sample of 35 firms and come from Mansfield et al. (1982). The 1975–81 figures come from National Science Foundation (1983). For various reasons, these data are rough.

There is a direct relationship between a firm's percentage of sales derived from abroad and its percentage of R&D expenditures carried out overseas. When sales from abroad are disaggregated, a firm's percentage of sales from foreign subsidiaries seems to have a positive effect on its percentage of R&D expenditures carried out overseas, while its percentage of sales from exports seems to have a negative effect. U.S.-based firms during the 1960s and early 1970s had an incentive to do R&D abroad because costs were lower there. According to a sample of 19 major firms studied by Mansfield, Romeo and Teece (1979), the mean ratio of the cost of R&D inputs in selected overseas locations to that in the United States in 1970 was 0.74 in Europe, 0.60 in Japan, and 0.86 in Canada. However, between 1970 and 1975, the cost differential was largely eliminated for many firms, owing in part to the depreciation of the U.S. dollar relative to other currencies. Of course, this helps to explain the fact that the percentage of R&D carried out overseas did not increase substantially after 1975. In fact, during 1980–82, there was a dip in overseas R&D spending, particularly in the transportation industry. According to the National Science Foundation (1983a), this reflected the strength of the dollar and the fact that the recession was more severe in foreign countries than the United States.

Since the term "research and development" covers an enormous range of activities, it is important to note that firms' overseas R&D activities tend to focus on development rather than on research, on product and process improvements rather than on new products and processes, and on relatively short-term, technically safe work. Based on a sample of 23 firms examined by Mansfield et al. (1982), about three-quarters of these firms' overseas R&D expenditures are aimed at product or process improvements and modifications, not at entirely new processes and products. This percentage is much higher than for all U.S. industrial R&D.

A very substantial percentage of Canada's industrial R&D is carried out by foreign multinational firms. In 1979, it amounted to 40 percent according to the Statistics Canada's Science Statistics Centre (1982, p. 36). This was substantially lower than in 1973, when it was 54 percent. Canada is one of the leading sites for the overseas R&D of U.S.-based multinational firms. In 1975, about 13 percent of all such R&D took place in Canada. However, according to the Conference Board (1976), Canada's share of such R&D declined during the late 1960s and early 1970s, while Germany's share increased considerably (Table 3-4). More will be said below about Canada's share of such R&D in the future.

TABLE 3-4 Distribution of Estimated R&D Abroad Sponsored by U.S.– Based Firms, by Country, Selected Years, 1966–75

	1966	1971	1972	1973	1975
			(percent)		
Canada	22.2	16.4	14.3	12.0	13.1
Britain	24.4	18.7	18.5	19.2	18.8
Germany	22.3	30.9	30.5	32.3	29.9
France	9.1	7.3	8.2	8.4	8.1
Belgium	3.2	3.4	3.5	3.5	3.5
Italy	2.6	4.9	5.0	4.2	6.1
Netherlands	1.7	2.6	2.9	3.1	3.0
Switzerland	1.1	1.6	1.8	1.8	2.0
Australia and New Zealand	4.1	3.8	3.6	3.6	3.7
Other	9.3	10.4	11.7	11.9	11.8
Total	100.0	100.0	100.0	100.0	100.0

Source: Conference Board, *Overseas Research and Development by United States Multinationals, 1966–75* (New York: The Board, 1976).

Reverse Technology Transfer

Because overseas laboratories have often been established to service and adapt product and process technology transferred by the U.S. parent to its foreign affiliates, it is often assumed that little of their work results in new technologies transferred back to the United States. In fact, a careful examination by Mansfield and Romeo (1984) of the experience of a sample of 29 such laboratories indicates that this is not true. About 47 percent of their R&D expenditures in 1979 resulted in technologies that were transferred to the United States. A major reason why overseas laboratories transfer so much technology back to their U.S. parents is that many of them no longer are devoted merely to the servicing and adaptation of U.S. technology. In time, they frequently begin generating new or improved products and processes expressly for foreign application, and some ultimately begin to produce technology for application throughout the world, including the United States.

The percentage of overseas R&D expenditures resulting in technologies transferred to the United States varies considerably among the laboratories. Some transfer all of the technologies to the United States while others transfer none. The explanation for these differences lies partly in the different functions established for these overseas laboratories. Obviously, those established to produce technology for worldwide application transfer more to the United States than those established to service or adapt technology transferred from the United States or to produce technology for foreign application. Holding the laboratory's function constant, the percentage of R&D expenditures resulting in technologies transferred to the United States seems to be directly related to a laboratory's size and to the percentage of R&D expenditures devoted to research (rather than to development). This seems reasonable because larger and more research-intensive laboratories do the more fundamental work that is more likely to be transferrable to the United States.

Existing evidence points to little or no time lag between the first appearance of the transferred technologies abroad and their first application in the United States. Indeed, in the electrical equipment industry, the average lag is negative. Because of the size and richness of the American market, firms tend to introduce technological innovations developed overseas — generally new products and product improvements rather than process changes — about as quickly in the United States as in their overseas markets. This is an important point, because it indicates the speed with which technology is transferred and the extent to which firms take a global view of the introduction of new products.

The foregoing discussion of reverse technology transfer is based on data concerning overseas laboratories of U.S.-based firms in a variety of countries, mainly in Europe. Since only a few of the laboratories are located in Canada, it is risky, of course, to assume that these findings apply to Canada. Without more data, all we can say is that to the extent that Canadian laboratories of U.S.-based firms are similar in this respect to other overseas laboratories of such firms, reverse technology transfer is by no means negligible.

Canada's Level of R&D Expenditures

Now that the rate and sources of technological change, the international transfer of technology, and the role of multinational firms in the transfer process have been examined, the next major issue concerns Canadian policy towards science and technology. Nothing seems to have stirred as much controversy as the apparently low level of research and development expenditures in Canada. The Minister of State for Science and Technology (MOSST) in 1978 announced a national priority of achieving a ratio of R&D expenditures to gross domestic product of 1.5 percent. This target was reiterated in 1980 and again in 1981.

The ratio of R&D spending to gross domestic product in Canada is lower than that in the United States, the Netherlands, Germany, Britain, France, Japan, Sweden, or Belgium. As Palda and Pazderka (1982) and others point out, the relatively low level of R&D spending in Canada may be the result of the structure of Canadian industry. Since over half of its manufacturing industry is foreign owned (Rugman, 1983), Canada benefits from a large amount of R&D performed outside Canada. As indicated in one MOSST (Canada, 1978) paper:

> Canada's domestically conducted R&D does not begin to approximate its total source of new technology, inasmuch as, being largely foreign-owned, Canadian industry has ready access to R&D imported from foreign parent companies. Significantly, much of this imported R&D enters the country without being financially recorded. . . .

According to estimates by MOSST, such "invisible" R&D imports in 1975 totaled more than $500 million.

There are many reasons why a market economy may under-invest in research and development. For one thing, because of externalities, firms frequently find it difficult to appropriate the benefits from their R&D. Certainly, it would not be surprising to learn that Canadian firms were under-investing in R&D. However, Canada's relatively low ratio of R&D spending to gross domestic product does not prove that this is true. What is needed is information concerning the social returns (and costs) from additional R&D in Canada. No attempts seem to have been made to obtain detailed estimates at the firm or project level concerning the social returns from Canadian investments in innovative activity, and econometric studies seem to have produced largely inconclusive results. One reason, according to some observers, is the lack of data concerning the "invisible" R&D transfers cited in the preceding paragraph. Thus, although there may well be some under-investment in R&D, much more data and analysis are required before the nature and extent of the shortfall can be estimated.

Tax Credits and Allowances

One way in which Canada has attempted to increase the level of R&D spending has been through direct tax incentives. Indeed, Canada has been a pioneer in the use of such devices. During the early 1980s, there was both an R&D investment tax credit and a special research allowance. The investment tax credit (which was taxable) was 10 to 25 percent of current and qualified capital expenditures on R&D, the percentage varying with the size of the firm and the location of its R&D facilities. The special research allowance permitted corporations to deduct from their taxable income an amount equal to 50 percent of the increase in operating and capital expenditures for R&D; these tax incentives were altered considerably in early 1984.

A survey conducted by Mansfield and Switzer (forthcoming) of 55 firms accounting for almost 30 percent of the company-financed R&D expenditures in Canada indicates that the investment tax credit in 1982 increased company-financed R&D expenditures (holding the definition of R&D constant) by about 2 percent, and that the special research allowance increased them by about 1 percent. The increases in company-financed R&D expenditures due to these tax incentives seem to have been considerably less than the cost to the government in reduced tax revenue. An econometric study by Mansfield and Switzer (forthcoming) based on data at the industry level is consistent with the survey results. Thus, the available evidence seems to indicate that these tax incentives have had only a modest effect on R&D spending.[7]

Studies have been carried out to estimate the generosity of the Canadian system of direct tax incentives for R&D relative to incentives offered by other world governments. According to McFetridge and Warda (1983), only one country — Singapore, which has a 200 percent write-off of R&D — is more generous in this regard. According to the Department of Finance (Canada, 1983), the after-tax cost of $100 of R&D was $36 in Canada, $52 in France, $47 in Germany, $55 in Japan, $44 in the United States, and $48 in Britain. In 1984, the R&D tax incentive system was changed. The special research allowance was eliminated, and the investment tax credit was increased by 10 percentage points. Also, firms were allowed to renounce their unused credits and allow outside investors to claim these incentives. Given that the new R&D tax incentive system has been in place for less than a year, there obviously is little reliable information concerning its effects.

Canada's Share of the R&D Efforts of Multinational Firms

A question posed at the beginning of this report is: Does Canada have any prospect of increasing its share of R&D effort of multinational firms? According to the Conference Board (1976), a country's share of the overseas R&D expenditures of U.S.-based multinational firms is related closely to its share of U.S. direct investment. Since Canada's share of U.S. direct investment fell during 1966–72, the Conference Board uses this fact to explain why Canada's share of overseas R&D by U.S.-based firms also dropped during that period.

In the years since 1972, Canada's share of U.S. direct investment has continued to decline, as indicated in Table 3-5. Moreover, when attention is confined to the chemical and machinery industries, both of which spend relatively large amounts on R&D, the pattern is the same. Thus, if the Conference Board is correct, one would expect Canada's share of the overseas R&D of U.S.-based firms to register a decrease during the past decade or so. The Board's data do seem to indicate that this was the case during 1972–75. However, I have not found a more recent set of compara-

ble published data showing the current geographical distribution of overseas R&D of U.S.-based firms.

If it is true that Canada's share of the overseas R&D of U.S.-based firms has declined, tax policies and other devices could still be constructed to attract more R&D to Canada. According to Frisch and Hartman (1984), if a foreign nation gives a good tax deal to an American multinational firm, the firm is likely to invest more money in that country. Similarly, such policies may have some effect, although not necessarily a major one, on R&D spending. However, as Horst (1981) shows, there are conditions under which firms do not reduce their worldwide tax liability by conducting R&D in the nation with the tax system that treats it most favourably.

Moreover, it must be recognized that there are a number of limitations on the amount of R&D that a multinational firm would tend to do in Canada. As Vernon (1974), Rugman (1983), and others point out, a multinational firm is likely to do a considerable amount of R&D near its corporate headquarters because of the importance in the innovation process of close communication and cooperation among R&D, marketing, production, and top management. Also, as stressed by a panel of industrial R&D executives recently (reported in National Science Foundation, 1983a), much of the overseas R&D done by U.S.-based firms is tied to the special design needs of particular overseas markets. Consequently, there are great advantages in doing R&D of this sort in close

TABLE 3-5 U.S. Direct Investment Abroad in Manufacturing in Canada and All Countries, 1966–81

Year	U.S. Direct Investment Abroad		
	Canada	All Countries	Canada's Share
	(millions of dollars)		(percent)
1966	6,697	20,740	32
1967	7,059	22,803	31
1968	7,535	25,160	30
1969	8,404	28,332	30
1970	8,971	31,049	29
1971	9,504	34,359	28
1972	10,491	38,325	27
1973	11,755	44,370	26
1974	13,450	51,172	26
1975	14,691	55,886	26
1976	15,965	61,161	26
1977	14,795	62,019	24
1978	15,736	69,669	23
1979	17,392	78,640	22
1980	18,877	89,161	21
1981	19,659	92,480	21

Source: United States, Department of Commerce.

proximity to these markets and in close contact with the relevant manufacturing units of the firm. For these reasons, it seems doubtful that Canada can attract a major proportion of the R&D of multinational firms.

Industrial Performance of R&D in Canada

The adequacy of a country's R&D may depend on the nature of the organizations that perform it, as well as on its total size. According to OECD (1979) figures, Canada performs a larger percentage of its R&D within the government sector than do most other industrialized countries. For example, 69 percent of Canada's R&D in 1977 was done by nonbusiness organizations (mostly government), whereas the comparable percentage was 56 in the United States, 59 percent in France, and 42 percent in Japan. Also, much of the government-financed R&D that is performed externally in Canada is done in universities rather than in firms. According to Pazderka (1983, pp. 17–18):

> It has been argued that the performance of a large share of a country's R&D activities by the government results in a weakness of the industrial sector, selection of inappropriate R&D projects and inadequate exploitation of results of research activities. (This may be so partly because private firms may not be aware of the results of government research and partly because these results may not be suitable for commercial exploitation.) This assessment has been shared and repeatedly confirmed by the Science Council of Canada, the National Research Council, and other interested parties.

The Canadian government in 1972 recommended that government-sponsored R&D be contracted to industry wherever possible; this directive was extended in 1977.

One of the obvious advantages of industrial performance of government-financed R&D performance is the enhanced possibility of commercially useful spinoffs. A study by Mansfield and Switzer (1984) of 40 government-financed energy R&D projects performed by industrial firms in the United States suggests that such spinoffs occur in about one-third of the cases. Moreover, this figure may understate the true percentage because the data pertain only to company-financed R&D resulting directly and almost immediately from these projects.

The spinoff from a government-financed R&D project seems to depend on whether the performing firm contributes to the formulation of the project's goals and strategies. Some projects are formulated entirely by the government, with little or no input of ideas from the performing firm. Others are based in considerable part on the suggestions of the firm or on the combined efforts of the firm and the relevant government agency. According to Mansfield and Switzer (1984), the probability of a spinoff is about 20 to 30 percentage points higher for the latter types of projects than for the former types, because firms tend to formulate proposals so

as to maximize the possibility and attractiveness of follow-on R&D into which the firm can invest its own funds.[8]

Technology Policy: Opportunities and Limitations

In the past 20 years, governments of nations, big and small, have become increasingly involved in policies designed to stimulate civilian technology. These policies have included government-financed R&D programs (in energy, for example), R&D tax credits, licensing policies, and a host of other measures — for example, those covering government procurement regulations or grants to educational institutions. In some nations, such as France and Britain, these policies have received widespread criticism; in others, notably Japan, they have appeared to be quite successful, particularly in certain industries such as semiconductors and machine tools.

Countries with open economies and with small domestic markets relative to the United States or Japan face quite different problems than larger countries in formulating technology policies of this sort. With regard to many kinds of fundamental research, such countries would be well advised to "free ride" on the work performed in the biggest countries, at least to some extent, because the results of such work is disseminated rapidly and cheaply. Even in development, it seems eminently sensible for such countries to obtain many relevant technological capabilities through the multinational firms, even though the relevant developmental activities do not take place on their soil.

However, for a variety of reasons (some essentially non-economic), nations often want to increase the amount of R&D done locally.[9] One way in which they try to achieve this is by imposing a variety of restrictions on multinationals in order to force them to do more R&D in their country and to exploit the results there. But the firms sometimes balk at these policies or evade them in one way or another. For example, in Europe, some foreign-owned multinationals have refused government R&D grants that required that the results be exploited within the country.

Another way in which governments try to increase local R&D is by granting subsidies, sometimes in the form of tax credits. While such subsidies have some effect, it often seems to be rather modest. Thus, in Sweden, the increase in company-financed R&D expenditures due to tax credits in 1981 was only about one-third of the loss in tax revenues. Roughly similar results were obtained for the United States in 1981–83. Interviews conducted in Spain suggest that the results are similar there. The results for Canada are discussed above.[10]

Still another way in which governments try to increase local R&D is by initiating and expanding work of this sort in government laboratories. This policy has the advantage of being direct, but great problems may arise from the lack of information flows or poor coordination between

the research and the production and marketing of the good. In such circumstances, the R&D is likely to be misdirected or at least neglected or resisted by potential users.

In view of the widespread adoption of these kinds of policies by so many governments, it appears they are believed to be worthwhile or at least worth trying. But because of the difficulties in measuring their effects, there is very little dependable evidence concerning their contribution to civilian technology, let alone whether their benefits have exceeded their costs. Nonetheless, the little evidence available seems to be consistent with the following four propositions.

First, technology policy in many countries is prone to over-emphasize research and development. For many purposes, the important thing is innovation or technological change, not R&D, which by itself has little or no value. Only when it is combined with marketing and production capabilities does it become important. Moreover, in many industries, many innovations are not based on any formal, sophisticated R&D. While R&D is by no means unimportant, governments sometimes give it (and the national R&D statistics) more attention than is warranted.

Second, governments sometimes tend to compartmentalize problems and assume that a nation's technological capabilities should be influenced by various forms of technology policy, rather than by economic, trade, or other policies. In fact, however, it seems likely that a nation's policies concerning economic growth and investment, competition and protection, taxes and entrepreneurship have much more effect on its rate of innovation than its policies concerning research and development. Thus, if one wants to stimulate innovation, the former areas may be more important than R&D.

Third, from many points of view, diffusion or imitation may be much more important than innovation. Japan, for example, was not the first to develop or introduce industrial robots, but it has accepted and deployed a great many more robots than has the United States. Moreover, it is often asserted that the effects of robots on productivity have been greater in Japan than in the United States. From an economic point of view, it is much more important for a nation to exploit a new technology successfully than to be the first to introduce it. Here again, the significance of entrepreneurship and of the institutions and freedom that nourish entrepreneurs should be emphasized.

Fourth, governments seem to be most successful in stimulating civilian technology when they emphasize relatively broad policies rather than attempting to make detailed decisions concerning which specific designs and types of commercial products should be developed and at what pace. There is little evidence that attempts by government agencies to assume the entrepreneurial role or to regulate in detail the inflow, outflow, and application of industrial technology have been successful, with the possible exception of Japan (about which there is considerable

controversy). On the other hand, policies which are widely regarded as having been important in promoting technological change and productivity growth include those designed to promote the quality and extent of education in science, engineering, and management, to build the vigour of competition among the nation's firms, to support fundamental research and to attain reasonably full employment with a reasonably stable price level.

Notes

This paper was completed in summer 1984.

1. For example, see *Business Week* (February 13, 1984).
2. The "other" industry consists of fabricated metal products, textiles, and paper combined.
3. Because fabricated metal products, textiles, and paper are lumped together into a single "other" category, there are 11, not 13, industries.
4. The term "overseas" as used here means all countries outside the United States, including Canada.
5. For an excellent discussion of the multinational firm, see Caves (1982).
6. For an interesting statistical study of the factors influencing the mode of transfer, see Davidson and McFetridge (1984).
7. Similar results were obtained by Mansfield (1984b) for Sweden and the United States.
8. Two points should be noted. (1) Although most studies have concluded that government-financed R&D has not tended to crowd out privately financed R&D, this is not true of all recent studies; in particular, Lichtenberg (1984) reaches the opposite conclusion. (2) Econometric studies generally indicate that R&D under government contract has a relatively small effect on the productivity increase of the industries performing it; however, it often may be more realistic to view government-funded R&D as a factor that facilitates and expands the profitability of privately funded R&D. See Economic Council of Canada (1983) and the references cited therein for further discussion of contracting out of R&D.
9. See, for example, McFetridge (1977).
10. See also Howe and McFetridge (1976) for an influential study.

Bibliography

Baumann, H. 1973. "The Diffusion of the Basic Oxygen Process in the U.S. and Canadian Steel Industries, 1955–69." Research Report 7303. London: University of Western Ontario.

Baranson, J. 1978. *Technology and the Multinationals: Corporate Strategies in a Changing World Economy*. Lexington: Lexington Books.

Canada. 1983. Department of Finance. *Research and Development Tax Policies*. Ottawa: The Department.

———. 1978. Ministry of State for Science and Technology. "Importation of Invisible Research and Development, 1974–76." Background Paper 3. Ottawa: The Ministry.

Caves, R. 1982. *Multinational Enterprise and Economic Analysis*. Cambridge: Cambridge University Press.

Caves, R., H. Crookell, and J.P. Killing. 1983. "The Imperfect Market for Technology Licenses." *Oxford Bulletin of Economics and Statistics* (August).

Conference Board. 1976. *Overseas Research and Development by United States Multinationals, 1966–75*. New York: The Board.

Contractor, F., and T. Sagafi-Nejad. 1981. "International Technology Transfer: Major Issues and Policy Responses." *Journal of International Business Studies* (Fall).

Daly, D., and S. Globerman. 1976. *Tariff and Science Policies: Applications of a Model of Nationalism*. Toronto: University of Toronto Press.

Davidson, W., and R. Harrigan. 1977. "Key Decisions in International Marketing: Introducing New Products Abroad." *Columbia Journal of World Business* (Winter).

Davidson, W., and D. McFetridge. 1984. "International Technology Transactions and the Theory of the Firm." *Journal of Industrial Economics* (March).

DeMelto, D., K. McMullen, and R. Wills. 1980. "Preliminary Report: Innovation and Technological Change in Five Canadian Industries." Discussion Paper 176. Ottawa: Economic Council of Canada.

Dirlam, J., and W. Adams. 1966. "Big Steel, Invention, and Innovation." *Quarterly Journal of Economics* (May).

Economic Council of Canada. 1983. *The Bottom Line: Technology, Trade, and Income Growth*. Ottawa: Minister of Supply and Services Canada.

Frisch, D., and D. Hartman. 1984. "Taxation and Location of U.S. Investment Abroad." Working Paper 1241. Cambridge, Mass.: National Bureau of Economic Research.

Globerman, S. 1975a. "Technological Diffusion in the Canadian Carpet Industry." *Research Policy* (Spring).

———. 1975b. "Technological Diffusion in the Canadian Tool and Die Industry." *Review of Economics and Statistics* (November).

Horst, T. 1981. "Impact of Income Taxes on the Profitability of Locating a Manufacturing Plant in Canada Versus the United States." Washington, D.C.: Taxecon Associates.

Howe, J., and D. McFetridge. 1976. "The Determinants of R&D Expenditures." *Canadian Journal of Economics* (February).

Kendrick, J. 1980. "Why Productivity Growth Rates Change and Differ." Paper presented at the Conference on Economic Growth, Institute of World Economics, Kiel, Germany, June.

Kroner, M. 1980. "U.S. International Transactions in Royalties and Fees." *Survey of Current Business* (January).

Lichtenberg, F. 1984. "The Relationship Between Federal Contract R&D and Company R&D." *American Economic Review* (May).

Mansfield, E., 1977. "The Diffusion of Eight Major Industrial Innovations in the United States." In *The State of Science and Research*, edited by N.Terleckyj. Boulder, Colo.: Westview.

———. 1980. "Basic Research and Productivity Increase in Manufacturing." *American Economic Review* (December).

———. 1984a. "International Technology Gaps and the Intelligence-Gathering Activities of Firms." Philadelphia: University of Pennsylvania.

———. 1984b. "Public Policy Toward Industrial Innovation: An International Study of Direct Tax Incentives for R&D." Seventy-fifth Anniversary Colloquium on Productivity and Technology, Harvard Business School.

Mansfield, E., and A. Romeo. 1980. "Technology Transfer to Overseas Subsidiaries by U.S.-Based Firms." *Quarterly Journal of Economics* (December).

———. 1984. "Reverse Transfers of Technology from Overseas Subsidiaries to American Firms." *IEEE Transactions on Engineering Management* (August).

Mansfield, E., A. Romeo, M. Schwartz, D. Teece, S. Wagner, and P. Brach. 1982. *Technology Transfer, Productivity, and Economic Policy*. New York: W.W. Norton.

Mansfield, E., A. Romeo, and D. Teece. 1979. "Overseas Research and Development by U.S.–Based Firms." *Economica* (May).

Mansfield, E., A. Romeo, and S. Wagner. 1979. "Foreign Trade and U.S. Research and Development." *Review of Economics and Statistics* (February).

Mansfield, E., and L. Switzer. 1984. "Effects of Federal Support on Company-Financed R&D: The Case of Energy." *Management Science* (May).

———. Forthcoming. "The Effects of R&D Tax Credits and Allowances in Canada." *Research Policy*.

McFetridge, D. 1977. *Government Support of Scientific Research and Development: An Economic Analysis*. Toronto: Ontario Economic Council.

McFetridge, D., and J. Warda. 1983. *Canadian R&D Incentives: Their Adequacy and Impact*. Toronto: Canadian Tax Foundation.

McMullen, K. 1983. "Lags in Product and Process Innovation Adoption by Canadian Firms." In *Multinationals and Technology Transfer: The Canadian Experience*, edited by A. Rugman. New York: Praeger.

National Science Foundation. 1975. *Science Indicators, 1974*.Washington, D.C.: U.S. Government Printing Office.

———. 1983a. "Dollar Value of U.S. R&D Expenditures Overseas Declined in 1982." *Science Resources Studies Highlights* (December).

———. 1983b. *Science Indicators, 1982*. Washington, D.C.: U.S. Government Printing Office.

Organisation for Economic Co-operation and Development. 1970. *Gaps in Technology: Analytical Report*. Paris: OECD.

———. 1979. *Trends in Industrial R&D in Selected OECD Member Countries, 1967–75*. Paris: OECD.

Palda, K., and B. Pazderka. 1982. *Approaches to an International Comparison of Canada's R&D Expenditures*. Study prepared for the Economic Council of Canada. Ottawa: Minister of Supply and Services Canada.

Pazderka, B. 1983. "Innovation Policies in Small Open Economies." Working Paper 1983–6. Kingston: Queen's University, School of Business.

Rugman, A., ed. 1983. *Multinationals and Technology Transfer: The Canadian Experience*. New York: Praeger.

Statistics Canada. Science Statistics Centre. 1982. "Standard Industrial R&D Tables, 1963–82." Ottawa: Statistics Canada.

Telesio, P. 1977. "Foreign Licensing Policies in Multinational Enterprises." D.B.A. diss., Harvard University.

Vernon, R. 1974. "The Location of Economic Activity." In *Economic Analysis and the Multinational Enterprise*, edited by J. Dunning. London: Allen and Unwin.

Corporate Operations and Strategy in a Changing World Environment

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From the early 1970s until the early 1980s, U.S. economic performance declined relative to its performance during the two previous decades. In response, there was an outpouring of theories and analyses of what is wrong with the U.S. economy and prescriptions for fixing it. For one group of critics, the failure of the U.S. economy to repeat its past performance or live up to their expectations of its potential was due primarily to a widespread, systematic failure of American firms to adjust and improve their operations and strategies in response to changes in the world technological, economic, and trade environment.[1] This paper presents a critical survey of the analyses and recommendations of this body of literature. It addresses four questions. What are the perceived failures of North American firms? What are the prescriptions for changes in their operations? What are the mechanisms by which these changes are to be implemented? What are the prospects for improvement through the end of the decade?

Since most of the important and influential analyses of the failures and prospects of North American firms have been directed toward firms south of our border, this paper, by necessity, tends to focus on American firms and American business practices. This emphasis immediately raises the question of the relevance of this paper to the concerns of Canadians in general and of members of this Royal Commission in particular. This question gains force when the many differences between the problems and operations of American and Canadian firms, and the differences in the American and Canadian industrial structure, economy and economic prospects and problems are taken into account. There are several responses to this question.

First, other papers for the Royal Commission have addressed the issues of Canadian economic performance, industrial structure, and the unique problems of Canadian firms — foreign ownership, economies of scale, productivity, costs, research and development, government ownership, export capability, and so on. Second, the high level of foreign, mostly American, ownership of Canadian firms implies that in large measure the problems and prospects faced by American firms in their operations and strategy spill over into their subsidiaries in Canada. Third, the theory and practice of business operations and strategy tend to drift from south to north, so that Canadian management practices are similar to those in the United States, but often with a lag. Fourth, if American managers can improve the operating performance of their firms, this may improve the prospects of the American economy — Canada's major export market — on the one hand, and increase the level of competition for Canadian producers and exporters on the other. Fifth, this paper is about operations and strategic management per se — past trends and future prospects — and hence is in large part as applicable to Canadian as to American firms. Throughout this paper and particularly in the last section, this analysis of corporate performance and strategy emphasizes the implications for Canadian firms and the concerns of the Royal Commission.

For all these reasons, an analysis of the problems that have been identified in American management are relevant to the concerns of the Commission. Two facts are clear: there has been significant change in the external environment of North American business over the past 15 years, and since the early 1970s the performance of American business has fallen short of its previous postwar performance and of expectations engendered by its previous success. It is important to ascertain what role, if any, management has played in the unsatisfactory corporate performance in America, how management performance can be and is being improved, and what role, if any, there is for government in this process.

To some extent, the wave of criticism of American management was triggered by the recession of 1980–82 and has subsided with the cyclical improvement of the economy during 1983–84. However, as one reviewer of this paper noted, firms, like nations, can become complacent, rigid and sloppy during long periods of growth and success. Economic hard times both bring these problems to the attention of management and force them to change their practices in the face of an adverse external environment. Quite apart from the recent cyclical downturn and recovery, however, there have been fundamental changes in the external competitive environment of North American firms (Daly, 1983) including:

- increased importance relative to the United States and Canada of Japan, Europe, and the newly industrialized countries (NICs) as markets, producers and exporters;

- a significant reduction in tariff and non-tariff barriers to trade and an increase in flows of capital;
- a dramatic increase in the level of world trade, especially in manufactured products; and
- an acceleration of the rate of technology diffusion.

All these developments have contributed to a high degree of turbulence and uncertainty for North American firms that is beyond the past experience of businessmen, politicians and civil servants. The effects of these long-term trends, although accentuated by the recent business cycle, will persist into the foreseeable future.

The problems experienced by U.S. firms in this turbulent environment are clear as well:

- loss of U.S. dominance in new technology (see the paper by Mansfield (1985) in this volume);
- the decline in the U.S. share of world production and trade in manufactured products;
- the increased import penetration in many U.S. manufacturing industries and, more recently, huge trade and current account deficits; and
- high and rising U.S. unit labour costs and falling rates of productivity growth.

In some respects these problems are more severe for Canadian firms. Productivity is lower and has increased more slowly in Canada than in its major trading partners, and unit labour costs are higher and have increased at a faster rate (Daly, 1983). Yet, as an open economy, Canada is highly exposed to imports on the one hand and must export in increasingly competitive world markets on the other. Hence, increases in productivity and lower unit labour costs are vital to Canada's continued economic success. During the downturn of 1980–82, Canada's gross national product and manufacturing output fell the most sharply among member countries of the Organisation for Economic Co-operation and Development, despite large and growing trade surpluses. Although the economy recovered slowly from this trough, unemployment, bankruptcies and plant closures remained high by past and international standards, and capital investment did not recover as is typical after a recession. Through 1984 the expansion has been fragile. These pieces of evidence suggest that the problems with corporate performance may be more serious in Canada than in the United States (see Daly, 1983).

Corporate Performance and Strategy

Recently, article after article and speech after speech have harangued U.S. managers and businesses for their inadequate, misdirected and counterproductive operations in all the functional areas of their business and in their formulation and execution of overall business strategy.

American management, once envied, extolled and emulated, has come to be denigrated, pitied and shunned. These critics conclude that although other factors may have contributed to the recent unsatisfactory performance of the U.S. economy, it is largely attributable to the failure of American management and American business. Lest this conclusion seem to be an overstatement, let me quote from some of the most influential writers on this subject, all at the Harvard Business School, the great bastion of managerial capitalism. For example, Abernathy, Clark and Kantrow (1983a) observe:

> We believe that "micro software" [corporate management, — organization, administration, and production systems] — what management does — is essential to the renaissance of a beleaguered American industry. . . . American manufacturers have gotten into trouble not because of general economic conditions or unfair trade practices but because they have lost the determination to manufacture well. . . . [Superior] competitive strategy . . . has enabled foreign producers to outflank, outfox, and outperform their American counterparts. (pp. 4–5)

Similarly, Hayes and Abernathy (1980) conclude:

> Responsibility for this competitive listlessness belongs not just to a set of external conditions, but to the attitudes, preoccupations, and practices of American managers. (p. 77)

In light of the other possible determinants of U.S. economic performance, these conclusions seem a bit harsh and one-sided.[2] Nevertheless, as the long list of books and articles in the bibliography of this paper attests, there is a deep-seated and widely held belief that American management has failed to manage well in a changing economic environment.

According to Abernathy et al., the failures of American business were masked during the 1950s and 1960s by the pre-eminence of the American economy after World War II and its relative isolation and independence from the world economy. Over time, however, transfer of broadly defined technology and capital mobility combined with growing management capabilities in firms outside the United States to make these firms strong competitors in their home markets, in world markets, and in the United States. At the same time, falling tariff and non-tariff barriers to trade, falling transportation and communications costs, and the homogenization of world income levels led to the globalization of many industries and to an increased trade exposure in many manufacturing industries in the United States.[3] Abernathy et al. conclude that U.S. manufacturing firms have not responded well to this "new industrial competition" and that they will be left behind if they do not reform in the future, much as many British firms (and the British economy) were left behind a century ago.

The charges of mismanagement by American firms range across all functional areas of business and go on to problems in the formulation and implementation of overall business strategy. Since these problems are interrelated, I will start with overall strategy to set the context of the problems in the functional areas.

The problems that have been identified in the management of American firms in their operations in the functional areas must be seen within the context of their overall strategic management. These concerns have focussed on three areas of strategy — the time horizon of American business; the focus on "paper profits" from mergers and acquisitions, and particularly from conglomerate diversification; and the lack of integration between the functional areas of business and overall business strategy. In the critiques of American business, the superior practices of Japanese firms have often been held up as role models to be admired, feared and copied. Although the purpose of this paper is not to give a comprehensive review and critique of the vast and burgeoning literature on Japanese management, by force of popular opinion some of its more salient points for the practice of American firms and government policy will be analyzed.

Time Horizon

Many of the critiques of American management conclude that American managers focus on short-term results, particularly short-term profitability and earnings per share, at the expense of the long-term profitability of the firm. Shetty (1982) concludes:

> The emphasis on short-term performance at the expense of long-term results and productivity has become endemic to American business culture. The horizons of the average American manager seem to be several years nearer than the horizons of most of his or her counterparts in other countries. . . . [Yet] a long-run perspective or orientation is vital for a business in a modern industrial society. (p. 39)

The short-term-result myopia is variously described as being caused by stockholders and security analysts who focus on quarterly earnings reports; control and reward systems ("three years up or out"); inbred and trained personal aggressiveness; greater mobility of American managers, especially those with MBA degrees; and the "reversed telescope" of discounted cash flow. Japanese managers are seen as less personally competitive and more oriented toward the success of their firm; less sensitive to short-term, external concerns arising from the stock market; less swayed by elegant but inappropriate financial techniques; and more concerned with operating fundamentals than American managers. The virtues of "Japanese-style" management have been extolled, and books and articles that show how American managers can achieve a similar

excellence have become bestsellers (Ouchi, 1981, 1984; Pascale and Athos, 1981; Vogel, 1978; Hayes, 1983; Kantrow, 1983; Bradford and Cohen, 1984; and Peters and Waterman, 1982).

There is a question, however, as to how much of the longer time horizon of Japanese firms can be explained by cultural, social and economic conditions in Japan that are not attributes of the Japanese management system per se and therefore could not be transferred abroad easily. For example, even if Japanese firms were to use the "reversed telescope" of discounted cash flow analysis in their investment decisions, four factors would lead them to use a lower discount rate and hence be more future-oriented than their American counterparts.

- Interest rates in Japan have usually been below those in other countries, and the government sometimes has subsidized them to even lower rates for certain industries.
- The capital structure of Japanese firms is relatively debt-heavy and debt is thought to be a relatively inexpensive form of finance (see Ellsworth, 1984).
- The relatively low use of external funds generated by the stock market partially isolates Japanese firms from the short-term pressures for profits which investors are said to place on American firms (see Ouchi, 1984).
- The Japanese government has acted through its industrial policies to reduce the risk (and hence the cost of capital) of firms in chosen "sunrise industries" through trade protection, government purchasing, and funding through the banking system.

Unless these factors were to exist for American firms as well, American managers could not be expected to have time horizons as long as those in Japan, even if they somehow could become Japanese-style managers overnight.

The ability of Japanese firms to obtain low-cost debt to invest in research and development, capital equipment and world market share gives them a powerful advantage in terms of a lower cost of capital. Moreover, Wright and Suzuki (1984) conclude that Japanese firms tend to regard debt much as American firms regard equity. Interest and debt repayment (often owed to banks within their group) are not fixed, but based on an ability to pay. Hence this debt is not only low cost, but also low risk (see also Tsurumi, 1982, pp. 88–92). In this way, Japanese firms acting within the umbrella of their group and the group's lead bank can gain access to low-cost, low-risk resources for expansion without much dependence on external funding sources such as the stock market. Wright and Suzuki also conclude that Japanese firms tend to regard dividend payments on their equity much as American firms regard interest payments. If at all possible, dividends are maintained at steady

levels through the business cycle, so that investors are less likely to focus on short-run fluctuations in profits.

Ouchi (1984, p. 71) shows how the combination of a lower cost of debt with a higher proportion of debt to equity has given Japanese firms a 25 percent lower cost of capital than similar U.S. firms, even when their costs of equity funds are roughly equal. In Ouchi's sample, some 37 percent of the equity of 135 Japanese electronics firms is held by banks (12 percent), insurance companies (8 percent), and other manufacturers (17 percent) within their group, so that management does not have to be concerned with fickle individual investors. Individuals hold less than 10 percent of the stock of 97 percent of the 1,005 largest publically traded firms which comprise the first section of the Tokyo Stock Exchange (Weiss, 1984, p. 124). Moreover, the stock of city banks in Japan is concentrated in the hands of several major industrial firms. For example, 27 percent of Mitsui Bank stock is owned by ten firms. This intercorporate ownership allows firms to operate more independently of the stock market, yet allows large, knowledgeable stockholders to influence management strategy and performance. Tsurumi (1982, p. 91) concludes that this system allows Japanese firms to operate with a lower cost of capital and a longer time horizon even in recent years when their debt/equity ratios have approached those of U.S. firms.

Even within the constraints of a higher cost of capital and hence a higher discount rate, however, many American firms are seen as focussing too much attention on short-term results. Tsurumi notes that during periods of economic downturn American firms lay off workers, cut investment, and reduce R&D expenditures in an effort to protect their bottom-line profits. In contrast, Japanese firms continue to invest in human and physical capital and long-run R&D even if these expenditures lead to reduced profits or losses in the short run.[4] Tsurumi concludes that this ability of Japanese firms to focus on the long run is the result of several institutional factors in the Japanese economy and society:

> The lack of predatory takeover practices in Japan left Japanese executives free to concentrate on long-term growth goals. . . . The absence of a "second-hand corporate market" discourages engineers and managers from taking their firms' R&D products to start new venture business. . . . (p. 90)

In other words, the ability, willingness and opportunity for American managers to change jobs, and the entrepreneurial spirit and risk acceptance of managers and scientists to start their own firms, force American firms to use a shorter time horizon. (Sethi et al., 1984, conclude that recently Japanese managers have become more footloose and more willing to strike off on their own.) These characteristics of North American managers are unlikely to change, and it is questionable whether the costs of restrictions on personal and capital mobility that

would be necessary to bring about such a change would be tolerated by American managers or the American public.

Donaldson and Lorsch (1983) present a startling departure from the accepted stereotype of the myopic investment behaviour of American managers based on an in-depth study of twelve mature and successful industrial companies in the United States. They conclude:

> This concern with corporate survival is the major reason for our discomfort with those who charge that American industry has given excessive priority to short-term profits or return on investment objectives to the neglect of long-term technological development, productive efficiency and capacity and competitive leadership. The corporate goals, priorities, and strategies we observed included short-term results; but they looked far beyond them as well. . . . At times financial exigencies dictated a disruption of long-term expenditure patterns in both operating and capital budgets. However, we did not observe chronic neglect. On the contrary, the foundation of future earnings was a persistent preoccupation of management. (p. 169)

Donaldson and Lorsch speculate that their conclusion may have been due to their selection of "successful" firms (where success was defined over the very long run). Several other interesting conclusions emerge from this study concerning the requirements for a firm to be able to follow a successful strategy:

> Most of these top managers chose to follow a policy of financial self-sufficiency. They did so because they had learned that the only truly loyal money was money over which they had direct control. . . . A high degree of financial self-sufficiency gives the professional corporate manager the opportunity to assert corporate financial priorities over those of his capital market constituency and to contravene the behaviour of transient shareholders or short-sighted portfolio managers that he considers counterproductive. To the career manager loyalty means everything and desertion is a punishable offense. . . . Further, financial self-sufficiency gives management greater leverage to resist capital market pressures likely to occur during the periods of change. (pp. 166–67)

Donaldson and Lorsch conclude that the "ultimate objectives" of the firms in the study were the maximization of "corporate wealth in its entirety — that is, the technical, market, and human resources under management's direct control, as well as the firm's financial resources" (p. 162). They point out that this "wealth" was not profits or stockholder wealth but was directly related to the power of the corporation to survive using resources under management control.[5] Donaldson (1984), in a subsequent book based on the same sample of firms, concludes that four goals particularly influenced management — survival (maintaining corporate purchasing power); independence from financial or regulatory commitments or individual product markets; self-sufficiency; and managerial success and self-fulfillment. The firms that were able to achieve

these goals were able to bet the long term because they were successful in unhooking themselves from the short-term pressures of the stock market and the product market, much as is the case for firms in Japan.

The conclusion that the stock market can exert harmful pressures on firms has led Bower (1983) to a somewhat different conclusion:

> We probably [will] have to give up the myth that ownership of shares of common stock of a widely held company is the same thing as ownership of a company, in the sense that ownership conveys a right to manage. . . . If we wish corporate management to take a more long-term comprehensive view, then we should not leave them vulnerable to whims of brokers seeking transaction fees who pretend that fictions such as quarterly earnings per share have any fundamental meaning. (p. 254)

Ironically (and amazingly) these strong charges against American managers and the dysfunctional effects of the American financial system do not come from "young Turks" or the radical left, but from mainstream full professors at Harvard Business School — Abernathy and Hayes (examining production), Lorsch (organizational behaviour), Donaldson (finance), and Bower (business policy). Yet most of the evidence on "managerial firms," in which management is isolated from the pressures of owners, suggests that they underperform "owner-controlled" firms in terms of profitability and efficiency. Unhooking American firms from the daily stock market pressures for short-term profits would seem to carry the potential for a further deterioration of performance unless some other control group were put in place. On this point, Tsurumi (1982) has several interesting conclusions:

> The "group capitalism" of post-war Japan possessed the functional equivalent of the best of West Germany's "financial capitalism," where the internal capital market of bank-client relationships assured efficient and timely allocation of capital. The Japanese system also had the best of the U.S. "managerial capitalism," where professional managers applied their own "visible hands" to allocate necessary resources to targeted projects. (p. 89)

Tsurumi contrasts this institutional structure for allocating resources with that of the prewar Zaibatsu and American conglomerates which were "slow to reallocate resources internally as well as to explore new technological frontiers." Thurow (1983) has called for the U.S. government to allow banks to act as merchant bankers and take minority positions in firms, as they can in Germany and Japan, in order to increase capital mobility and to reduce the short-term pressures on firms from the stock market. Recently, however, there has been considerable controversy over the role of banks in Germany and their links to manufacturing firms through equity holdings. Some critics have charged that this relationship has pushed stability and isolation from the stock market to the point of paralysis and obsolescence. The problem then would seem to be

in reducing the existing pressures for short-term profits while at the same time keeping management on its toes so that it responds to long-run, fundamental strategic changes in the firm's environment.

Charges that investors and firms in the United States are dysfunctionally short-sighted would seem to have a major theoretical flaw. If firms and investors were indeed dysfunctionally short-sighted, this would seem to present an opportunity for firms with a longer time horizon to out-compete and out-perform them in the long run, and for investors with a longer time horizon to make supernormal profits. Given the high level of industrial competition and capital mobility in the United States, there would seem to be no reason why some firms and investors would not follow strategies with an appropriately long time horizon if such a strategy would indeed lead to increased profits and stockholder wealth.

Despite some perceived problems, it is also difficult to fault the basic workings of the U.S. financial system, beyond anomalies introduced into it by government taxation policies. The amount of funding available to new, risky investments with long gestation periods, such as in biotechnology and microelectronics, is staggering and the envy of entrepreneurs around the world.

The allegations of a dysfunctionally short time horizon in American business might also be directed toward business in Canada. First, there is the oft-cited low level of R&D among Canadian firms. Arguably, foreign subsidiaries can overcome this by licensing product and process technology from their parent abroad. Yet Canadian-owned firms also have low levels of R&D, and their ability and willingness to access information on foreign technology seems to be severely constrained (see the paper by Bishop and Crookell for this Royal Commission and Killing, 1978). Crookell and Bishop (1983) cite the unwillingness of Canadian-owned firms to engage in risky long-term R&D as one of the major problems of Canadian-owned firms in the 1980s. Managers in Canadian-owned firms are also generally seen to be more risk averse and conservative than U.S. managers. This has two effects. It raises the discount rate for investment analysis and hence shortens the time horizon, and it can also lead firms to discriminate systematically against high-risk investments in R&D, market penetration, exports and major capital projects. There may also be inefficiencies in Canadian capital markets which increase the difficulty of small firms and entrepreneurs to access capital for expansion, investment and R&D (Hatch, Wynant and Grant, 1984).

Mergers, Takeovers and Conglomerate Diversification

The "merger mania" of American managers, as well as their pursuit of other means to "paper profits" through "paper entrepreneurialism,"

have come in for particularly harsh words. To quote Reich (as cited in Fallows, 1980), American managers devote their energies to "establishing joint ventures, consortiums, holding companies, mutual funds; finding companies to acquire, white knights to be acquired by, engaging in proxy fights, tender splits, spinoffs, divestitures; going private, going public, going bankrupt" (p. 23). Reich (1983) devotes an entire chapter to "paper entrepreneurialism," which includes mergers and takeovers but extends to a host of financial, accounting, taxation, personnel, public relations and legal practices, as well as lobbying of government. Reich concludes that these activities add nothing to the productive capacity of the firm or to the economy as a whole. Worse, paper entrepreneurialism uses up the energies and talents of the "best and the brightest" while at the same time breeding both personal insecurity and hierarchical rigidity.

Perhaps Reich's harshest words are reserved for conglomerate diversification:

> Conglomerates serve no useful financial purpose. . . . American investors gain nothing . . . [and] conglomerates undermine the efficiency of America's capital market. . . . Nor do conglomerates serve any useful industrial purpose. . . . Modern conglomerates are generally little concerned with the actual economic functions of the various subsidiaries, beyond the interest a landlord takes in a sharecropper's labors. . . . Nor do they benefit employees. When one of a conglomerate's businesses begins to falter, only capital assets are salvaged and redeployed. Workers are typically left to fend for themselves. (pp. 150–51)

The literature on the performance of conglomerates generally supports these conclusions, if with somewhat less rhetoric.[6] Mason and Goudzwaard (1976) conclude that the conglomerates in their sample did not perform as well as their "mirror portfolios" in terms of return to the shareholder or return on assets.[7] Hill (1983) finds that in Britain from 1970 to 1976 return on sales and return on capital were more variable over the business cycle for conglomerate firms than for other firms. Hill concludes:

> Thus, although conglomerates and concentric firms have often diversified to a similar degree, it is the concentric diversifiers which register the more consistent performance. . . . Whereas the top management of a concentrically diversified firm understands the nature of the business in which it is involved, the top management of a conglomerate firm does not. (p. 210)

Cisiel and Evans (1984) conclude:

> The experience of the 1970s recessionary periods suggest that there are serious managerial diseconomies of diversification seen in recessions. Likewise, the inferior performance of highly diversified firms indicates that managerial diseconomies exist even in expansionary times. (p. 70)

Top managers and directors of highly diversified firms may fail to understand the determinants of success in each of the industries in which their firms operate. They can therefore become vulnerable to oversimplification of issues and shallow understanding of the problems and opportunities facing their firms in the many diverse industries in which they operate. This situation has led firms to increase their emphasis on financial controls based on return on investment for performance measures and discounted cash flow for investment evaluation.

Firms which engage in conglomerate diversification, however, may have little option. Lecraw (1984a), using a sample of large firms in Canada, concludes that the characteristics of the base industries of firms and their own characteristics largely determined the diversification path they followed. Conglomerate firms did perform below the average of other firms, but if a firm whose base industry characteristics indicated a strategy of conglomerate diversification followed another diversification strategy, its performance was also penalized.[8] In other words, conglomerate firms may have had little choice other than to be conglomerates, given the base industries in which they operated.

Donaldson and Lorsch (1983) also conclude that management's strategic choices were constrained by the characteristics in the industries in which the firm operated:

> Top management's freedom to set strategic direction in the mature industrial corporation is significantly constrained. The necessity to protect a competitive position commits the enterprise to a rate of growth and of investment largely defined by the industry (or industries) in which it operates. . . . This description clearly contradicts the popular motion of the senior corporate executive who can move mountains with a memo. . . . This is not to say that management has no choice in defining a meaningful financial goals system and strategy. . . . Yet, on balance, we remain most impressed by the constraints on top managers' choices. (pp. 172–73)

Donaldson and Lorsch also reach several interesting conclusions regarding the motivation for corporate diversification:

> The desire of top executives to put some distance between themselves and their particular product market constituencies was likewise evident in their product market strategies. . . . The corporate managers of these firms have beliefs about their limitations as well as their strengths, and they look for businesses they can manage successfully. . . . The effects of such corporate diversification on the product market constituents in the base industries are marked. Customers, suppliers, labor unions — the power of each is weakened by successful diversification strategy. . . . From management's perspective the firm's value has been increased through diversification because the uncertainty about its viability and ultimate survival has been reduced. . . . In those instances in which we observed managers "underinvesting" in declining businesses, they were actually relocating

> resources, because in their judgement, corporate survival demanded a shift to more promising product markets. (pp. 167–69)

As mentioned previously, the firms studied by Donaldson and Lorsch were not a random sample from among U.S. industrial firms, since by design they studied "successful" firms. But although Donaldson and Lorsch do not take this step, their positive description of the strategies of successful firms might well be taken as a normative prescription of what managers of firms should do. In this normative mode, Harrigan and Porter (1983) conclude that there is a wide range of strategies which can be followed by firms in declining base industries — the correct strategy depending on the characteristics of the industry, the firm's competitors, and the firm itself. Disinvestment (harvest), diversification and exit are only three of the possible strategies, and not necessarily the optimum ones. Other potentially successful strategies include further investment to achieve a cost leadership position, focus on non-threatened product niches, foreign direct investment, and vertical integration to control suppliers or customers.

On the other hand, Tsurumi (1982) concludes:

> Compared to large American firms, large Japanese firms are characterized by narrower product lines. . . . This single-minded pursuit of technological innovations in roughly the same market or product area is in contrast to the "portfolio paradigm" used by many American firms to rationalize their premature abandonment of existing products and markets. . . . Japanese manufacturers prefer to seek "more knowledge intensive ventures" in their familiar product market lines. (pp. 90–91)

This focus on technological advance within one relatively narrow product line has had two favourable implications for Japanese firms. It has allowed them to operate "focused factories" (Skinner, 1983a) with narrower product lines, fewer line changeovers, lower inventories, more dedicated machinery, higher productivity, and more consistent quality. It has also allowed them to take advantage of the "dematuring" which has occurred in many industries (Abernathy et al., 1983b). In contrast, American firms have tended to diversify out of mature, "declining" industries, rather than to invest in further product and process technology.

Based on their analysis of the automobile industry in the United States, Abernathy et al. (1983b) conclude that technological change can allow, and in fact requires, a "de-maturing" of broad sectors of basic American industries such as automobiles, steel, chemicals, rubber, machine tools, consumer electronics, and so on. They conclude that American firms have, can, and must take advantage of the opportunities provided by new product and process technology to "de-mature" in their base industries so that they do not have to compete head-on with firms abroad in standardized products made by standard-

ized production technology. Their prognosis for American industry is guardedly optimistic:

> Advances in product and process design, a conscious effort to tear down the barriers that have grown up between manufacturing and the other functions, a deliberate effort to encourage ongoing communication at all levels, and a willingness to learn from experience and to follow the possibilities of new technology — these are the minimum requirements for building a new manufacturing paradigm. . . .
>
> We have seen [these developments] take shape in dozens of companies, never in quite the same form but always directed toward the same end: building organizations that are absolutely first rate in the work of technology-based manufacturing. (p. 127)

Two examples can illustrate the opportunities and problems of following a "de-maturing," technology-based strategy within a firm's base industry. In the early 1970s, the U.S. tire industry was under extreme pressure from Michelin's steel-belted radial tires. The president of Goodyear announced that the firm was betting the bank on R&D and investment in tires to regain its lost markets. The day after the announcement, Goodyear's stock fell three points. By the mid-1980s, Goodyear had made several major product and process innovations and was highly profitable; at the same time Michelin had lost $900 million in two years on its operations. On the other hand, over the same period, U.S. Steel followed a conscious strategy of harvesting in its steel operations and diversifying into other unrelated industries, while Japanese steelmakers followed a "de-maturing" strategy of heavy investment and R&D (Krugman 1984). In the early 1980s, U.S. Steel was far more profitable in its total operations and even in its steel operations than were Japanese steel producers, despite their efficiency and technological superiority. A strategy of de-maturing by investment and R&D within a firm's base industry (as recommended by Abernathy et al., 1983a, and Hayes, 1983) would not seem to be appropriate for all firms in all industries.

Data on firms which engage in mergers and takeovers (as acquired or acquiring firms) do not support the conclusion that these activities are generally counterproductive. In a survey article, Jensen and Ruback (1983) conclude:

> This evidence indicates that corporate takeovers generate positive gains, that target firm shareholders benefit, and that bidding firm shareholders do not lose. The gains created by corporate takeovers do not appear to come from the creation of market power. With the exception of actions that exclude potential bidders, it is difficult to find managerial actions related to corporate control that harm shareholders. (p. 5)

Song (1983) finds that firms made their diversifying acquisitions to "achieve significant structural matches between acquired and acquiring companies, to exploit strengths and to avoid weaknesses in growth,

profitability and liquidity" (p. 97). Yip (1982) finds that in general firms chose their mode of diversification on a rational, economic basis (not opportunities for paper profits): "The choice between the two entry modes [acquisition and internal development] is well explained by measures of [entry] barriers and relatedness" (p. 332). Weston and Chung (1983) conclude:

> The preponderance of empirical evidence supports the judgement that merger activity is rational value maximizing behavior. On average, the total gains . . . are positive. Thus the evidence does not support the managerialism theory which holds that managements resort to mergers to increase the size of firms and increase their own compensation, or for the prestige of running giant organizations. . . . All [studies] interpret their results as supporting the efficiency theory [for mergers]. . . . Thus, mergers appear to represent a response to the characteristics of the economic environment [including tax factors], facilitating resource reallocations within that environment. (pp. 47–48)

Linn and McConnell (1983) conclude that even the protective devices and strategies employed by management of potential takeover targets benefited the shareholders of their firms. Malatesta (1983) concludes that the return to shareholders of acquired firms was below average for the five years prior to the acquisition but above average afterward — that is, firms acquired poor performers and increased their performance after acquisition.

These studies paint a very different picture of the motivation and the effects of corporate takeover activity to that by Reich (1983), Magaziner and Reich (1982), Abernathy et al. (1983a), and others. If the market system were working efficiently, firms would be penalized if they expanded their operations into diverse industries to the point at which their internal markets are less efficient than the external market (Williamson, 1975). There is considerable evidence that conglomerates have sold off unprofitable subsidiaries as well as ones that could not be integrated into their other lines of business and overall competitive strategy. Porter (1976), however, finds that conglomerates had a lower propensity to sell off losing subsidiaries than did other firms. When they finally did sell off a losing subsidiary, they were often forced to take massive write-offs against equity.

In these cases of unsuccessful diversification, the discipline of the product and stock markets seems to have worked to force firms to operate efficiently. If market discipline has failed to function, the first best solution would be to remove the causes of this market failure rather than to restrict merger activity by law. As an example of a measure designed to reduce takeover activity, the U.S. government in 1983 was considering a tax regulation that would disallow deducting interest on funds borrowed for takeover bids as an expense for tax purposes.

Without changes in the market for financial assets and the tax system, there is every prospect of an increased, not decreased, level of conglomerate mergers (Salter and Weinhold, 1982).

Paper entrepreneurialism takes other forms. Increasing government involvement and regulation in the economy has increased the importance of lobbying by business to prevent or modify laws and regulations that would adversely affect the firm, and to advocate those that would help it. Large amounts of legal and management time have been devoted to manoeuvring firms through the increasingly complex and restrictive legal and regulatory thickets. This environment also gives a firm an incentive to compete with its rivals via litigation when it finds itself at a competitive disadvantage (Reich, 1982; Thurow, 1980). There is little prospect for these types of paper entrepreneurialism to subside in the United States unless government regulation of the microeconomy is reduced.

The implications of the analysis in this section for Canada depend on the conclusions about the efficiency effects of conglomerate diversification — whether it is seen as benign or dysfunctional. Canadian merger activity has tended to follow that in the United States, and the number of conglomerate mergers in Canada has come in waves and increased over time. Moreover, in Canada there are a large number of financial conglomerates — that is, firms in which overall management control is exercised via financial control through holding companies, rather than at the operating level. These are the types of firms that have been identified as the poorest performers (Canada, Royal Commission on Corporate Concentration, 1978, p. 110). Given the relative scale inefficiency and high product diversity of plants in Canada, there is a greater risk of having large conglomerate firms whose size does not translate into scale efficiency at the level of individual business units.

There is no necessary relationship between conglomerate diversification at the firm level and product diversity at the plant level; a conglomerate's units can operate rationalized plants. Product diversity and scale economies at the plant level are probably more important problems for Canadian industry than conglomerate diversification. The causes of the greater product diversity in Canadian firms and plants have long been known. The generally inward-looking nature of the Canadian manufacturing sector combined with Canada's relatively small internal markets and relatively high trade barriers have created opportunities for firms in many manufacturing industries to produce a wide line of products profitably even at a sacrifice of production efficiency. The high level of foreign ownership of subsidiaries may have compounded this problem. (But see Baldwin and Gorecki's paper for the Commission which concludes that there is no "miniature replica" effect.) Canada's relatively concentrated industrial structure has also motivated firms toward unre-

lated diversification since, if a firm reinvests in its base industry, industry output will increase and the oligopolistic consensus might be disturbed.

As Crookell and Bishop (1983) show, one of the major challenges facing Canadian industry in the 1980s is to respond to the tariff reductions achieved by the Tokyo Round of the General Agreement on Tariffs and Trade (GATT). Foreign-owned subsidiaries may respond by gradually ceasing operations in Canada and supplying Canadian markets from their home countries; rationalizing production across countries; or acquiring world product mandates. All three alternatives will create considerable difficulties for these subsidiaries, but Crookell and Bishop conclude that foreign-owned subsidiaries can deal with these problems if there is a certain amount of understanding by government in the formulation and implementation of policies and programs directed toward the manufacturing sector. For Canadian-owned firms, however, Crookell and Bishop find the outlook more bleak and uncertain. Canadian-owned firms face the same three alternatives (the first one being gradually to wind down their business in toto) but they will not have immediate and easy access to the necessary international network of intermediate and final product suppliers and export markets or the inexpensive access to product and process technology which are available to foreign-owned subsidiaries from their parents. Hence, their struggle to reduce the diversity of their product lines and increase their efficiency will be more difficult. (See the paper by Daly (1985) on this important point.) Despite these obstacles, studies for this Royal Commission by Daly and by Baldwin and Gorecki find that during the 1970s, both foreign and Canadian-owned firms in Canada were able to rationalize production significantly and to increase their scale. Further product rationalization to increase efficiency and competitiveness is a major challenge for Canadian industry and government in the 1980s.

Strategic Integration and Global Competition

Despite the prominence of formal strategic planning in many large American firms, there is a general feeling that their overall strategy formation and execution has failed in two important respects.

- In formulating and implementing strategic plans, the major functional areas — marketing, production, human resources and R&D — are not sufficiently linked and integrated.
- Firms often overlook the global competitive aspects of their strategy.

Again, Japanese firms have been held up as a role model. In Japanese firms, there is a much closer integration between the functional areas of operations than is generally the case within American firms. Integration is accomplished by rotating managers among the functional areas during

their careers, by reaching decisions through consensus, and by successive iterations both among functional departments and up and down the firm's hierarchy during the planning process. The Japanese strategic planning process typically starts with a fundamental analysis of worldwide trends in product markets in order to position products on the product cycle for income-elastic products (Tsurumi, 1982). After product needs and desired characteristics have been identified, a group is formed between marketing, R&D and production to develop a product which meets the characteristics demanded in the market and can be produced efficiently (at low cost) with high quality, low risk of product failure, and low service requirements. These essential characteristics are designed into the product rather than being forced onto the product department after the product has been designed to fit market demand or has been developed as an output of the R&D department.

In American firms, the planning process is often more linear and nonintegrated. For example, market research may identify an emerging need for a new product or product modification. The R&D department will develop and design the product to the specifications set by the marketing department, and then the product will be given to the production department to manufacture. The production department will have little input into the characteristics or design of the product based on the cost, quality control, inventory or service implications of a particular product design. Information usually flows upward through each department and is amalgamated and synthesized at the top, with executives representing each functional area acting as advocates of the position of their department. Alternatively, a new product or process may be generated in the R&D department in isolation from the marketing or production departments, with consequent problems in marketing and production. Home microcomputers may be a case in point — a technological triumph in search of a consumer need. Interestingly, Japanese firms have not been a significant factor in this market.

Some American firms have tried to resolve these problems through various organizational structures, such as matrix organizations, but the information flows, control and evaluation problems have proved to be severe. Some large firms have experimented with decentralizing the total responsibility for a new product by creating in-house, venture capital firms. This recent development is similar in many respects to the organizational structure of the large Japanese trading firms.

Beyond integrating production, R&D and marketing strategy, is the problem of aligning a firm's overall business strategy within the context of global markets, global technology generation and dissemination, global production opportunities and global competition. American firms have tended to focus most of their attention on technology, production and market developments in the United States. To the extent they have considered the rest of the world at all, they have viewed it from an

American perspective. The increased speed of technological diffusion, capital mobility and rising management expertise and experience around the world have led to global competition in many industries. In such industries, developments worldwide have implications for competition in all countries, and conversely, any competitive move in one country or market has worldwide implications. Hout, Porter and Rudden (1983) give an example of Caterpillar Tractor as a successful global competitor. Caterpillar invested in world-scale production facilities worldwide, but tailored its products to each market (thereby gaining economies of scale, economies of scope and market acceptance). The company committed financial resources to its products and did not diversify into unrelated products. It invested in Japan in partnership with the number two Japanese producer, Mitsubishi, to block the expansion of its major competitor Komatsu. By this strategy, Caterpillar was able to deny Komatsu a strong base at home from which to expand abroad while at the same time raising the barriers to entry into its markets worldwide.

American firms can and have successfully blocked Japanese and other multinational enterprises in their drive for world market share. However, many American firms have retreated in the face of what often appeared to be a furious Japanese onslaught. Yet Japanese firms, like all firms, do not have unlimited resources. Executives in Japanese firms are often surprised at how easily North American firms cede markets in the face of a threat. In fact, in some instances they have exploited the Japanese image as unstoppable kamikazes with no concern for profits to bluff their competitors out of attractive markets and new products. In an increasing number of industries, a firm must compete on a worldwide basis if it is to take advantage of opportunities to reduce production costs, access and develop technology, and gain global market share and sales volume. Such global competition often necessitates competing head-on with Japanese firms (Watson, 1983).

Canadian firms will increasingly have to turn toward a more global strategy as the protection of their domestic markets is progressively reduced under the tariff reductions of the Tokyo Round of the GATT (Daly, 1984). This transition will be difficult since many Canadian firms, particularly those in the manufacturing sector, are not as outward-looking through trade, licensing or foreign direct investment as are American, European or Japanese firms (Daly, 1984, Crookell and Bishop, 1983). To take the next step from looking outward (that is, outward from Canada) to global competition will be even more difficult and represents another major challenge for Canadian industry. There are notable exceptions to this generalization, such as Moore Corporation, Bata, Northern Telecom, Massey Ferguson, Mitel, MLW, Bombardier and several engineering consulting firms, but these are only a handful compared with what is necessary for Canada to be a successful global competitor.

Management of Financial, Product and Human Resources

Financial Analysis

One of the jewels in the crown of modern American managers, it was thought, was financial analysis. Critics of American financial managers, however, see them concentrating too much on the short-run impact of investment decisions on profits, earnings per share, and stock prices, and not enough on the long-run implications of their investment decisions.

Economic and financial theory have firmly established the criteria for evaluating investments in capital equipment, R&D, new products and so on. The procedure for evaluating an investment proposal is to discount back the expected future net cash flows at the risk-adjusted, required (market) rate of return (i.e., the cost of capital). This procedure of discounted cash flow (DCF), if correctly applied, is thought to maximize the value of the firm to its stockholders. DCF allows the manager to relate future cash flows generated by an investment to present cash outflows required by it. DCF can be shown to be superior to evaluating investments using average return on investment, years to payback, or impact on earnings per share, precisely because it does take the future into account.

The strongest critique of American financial practices attacks the very use of DCF as an evaluative tool. Hayes and Garvin (1983) write:

> We submit that the discounting approach has contributed to a decreased willingness to invest for the following reasons: (1) it is often based on misperceptions of the past and present economic environment, and (2) it is biased against investment because of critical errors in the way the theory is applied. Bluntly stated, the willingness of managers to view the future through the reversed telescope of discounted cash flow is shortchanging the futures of their companies. . . . (p. 37)

These are strong charges. The authors believe that using discounted cash flow is incorrect not only in theory but also in practice; because it is so difficult to apply correctly and managers are so prone to misuse it, it should be rejected. If only the direct effects of purchasing a piece of equipment (for example, cost reduction) are included, while its more difficult-to-quantify indirect effects such as changes in quality, speed, flexibility, worker skills, and so on, are excluded from the calculations, then use of discounted cash flow will yield incorrect results. Yet it is precisely these effects that may be the most important ones arising from a particular investment, and often the larger and more strategically important the investment, the more important these "secondary" effects. Hayes and Garvin conclude that financial managers who use DCF fall so in love with its elegance and technical precision that they use it blindly and ignore all the indirect effects of an investment that cannot be reduced to precise numbers.[9]

Incorporating risk into the DCF calculation may also pose problems. If a firm's average cost of capital is 12 percent, the appropriate discount rate for an individual project depends on the impact of this project on the firm's overall risk. Typically, firms incorporate risk into their analysis by increasing the hurdle rate of an investment — the discount rate used in DCF — depending on the risk of the individual investment, not its impact on the firm's overall risk level. Expenditures on R&D, new product launches, entry into new markets, and major capital acquisitions are typically assigned higher individual hurdle rates, and minor cost reductions or product modifications are given lower ones. Two major problems have been identified with this procedure.

- When risk is evaluated on a project-by-project basis, the risk to the firm as a whole from a strategic point of view of not undertaking the investment is often overlooked in focussing on the project's individual risk.
- Each investment strategy implies a set of future opportunities (options) which will be foregone if the investment is not made (Myers, 1984). Evaluating the value of these options over different investments may be extremely difficult or even impossible, since the options may not be known unless the investment is made. But if their value is not included in the DCF analysis, investments with "high option contents" — such as R&D, large-scale capital investment, and entering new markets — may not be made based on standard DCF analysis. Hence, DCF as it is applied by American firms may have led to the systematic discrimination against investment in R&D, capital plant and equipment, and global market share.

If discounted cash flow should not be used, what should replace it? Hayes and Garvin (1983) suggest that "Beyond all else, capital investment represents an act of faith, a belief that the future will be as promising as the present, together with a commitment to making the future happen" (p. 49). This recommendation seems to be extremely vague and non-operational, especially when compared with the precision and analytical rigour of discounted cash flow. It is, however, representative of the conclusions reached by many businessmen and academics. If a firm invests in developing and producing products which fill consumer needs, are of high quality and competitive in cost, this strategy will lead to the long-run success of the firm whatever the discounted cash flow calculations show for an individual investment. This investment decision rule, however, raises as many questions as it solves. It throws out the baby (rigorous, objective investment analysis) with the bath water (oversimplification at the altar of precision). How then should a firm approach its strategic investment decisions, and what is the proper use of DCF in those decisions?

Considerable research has been done on the relationship between financial capital budgeting and strategic analysis. (See, in particular,

Ellsworth, 1983; Donaldson, 1984; and Schoeffler, 1974.) In general, American firms place DCF (or return on investment, ROI) at the top of the list of investment criteria and Japanese firms place it at the bottom of the list. Tsurumi (1982), based on a comparison of American and Japanese firms, concludes:

> American firms' increased use of the discounted cash flow method of evaluating investment projects has caused them to treat every investment proposal as a separate and discrete unit. . . . Projects which promise large short-term cash flows are favored over long-term projects with greater uncertainties. (p. 92)

Tsurumi contrasts U.S. financial evaluation with that employed by Japanese firms:

> Japanese firms do not evaluate every investment project as a discrete and incremental addition to their business. Instead, they treat respective investment projects of R&D, expansion of production capacities and market development as integral parts of overall business whose global competitive postiions need to be advanced. (p. 92)

The decentralized, divisional structure of American firms encourages the use of DCF as a financial evaluation and control mechanism to rationalize decision making at the top across the firm's many strategic business units. Yet it is precisely at this strategic level with its "high option content" that DCF may be most prone to give incorrect conclusions.[10]

Hayes and Abernathy (1980) decry the practice whereby "the business strategist and marketer proposes, the financial analyst disposes," for fear that American firms are "managing our way to economic decline." What is necessary in their view is for North American firms to focus more on global strategic competitive and market analysis, combined with technology and production efficiency, and to give less emphasis to financial analysis. This realignment will be difficult since the finance departments and financial executives have risen to positions of power and authority in many American firms, and they are armed with a powerful body of theory and technique with which to press their position (Donaldson, 1984). Their position is further strengthened since the effects of misapplied financial analysis will appear only gradually over time in the long-run decline of the firm, while the effects of an unsuccessful R&D project, the launching of a new product, entry into a new market, or a major capital investment are often more obvious and immediate.

This is not to say that financial analysis using DCF is necessarily wrong per se or that investment based on a "belief in the future" must reign supreme. Firms should continue to disinvest in fundamentally unprofitable industries since privately owned firms must recover their cost of capital in the long run or go bankrupt. Hayes' conclusion[11] that "If we don't invest in tomorrow, tomorrow won't happen" is true as far

as it goes. His implied converse, however, that if we do invest in tomorrow, tomorrow will happen, is not correct. As the example of the steel industry in Japan graphically illustrates, investment based on this belief not only hurts the firms in the industry through low long-run profits, but also drains capital from other, more profitable and dynamic sectors of the economy.

For Canadian firms, there is a "good news–double bad news" situation. In general, Canadian firms have been relatively late in adopting DCF for their capital investments. But when they do use DCF they tend to use more conservative (higher) discount rates and when they do not, they usually use even more inappropriate financial techniques such as years to payback or average return on investment in five years.[12]

Production

The importance of excellence in production under the current "new industrial competition" is most forcefully stated by Abernathy et al. (1983a). They conclude that "Managers must recognize that they have entered a period of competition that requires of them a mastery of a technology driven strategy, of efficient and high-quality production, and of competent work-force management" (p. 9). These conclusions are echoed and reinforced by Hall (1983), Skinner (1983a, 1983b), Meal (1984), Hayes (1983), Wheelwright (1981), and Shetty (1983). These authors have identified several factors that have distracted management from pursuing excellence in production — the allure of financial sophistication and the "paper profits" of mergers and acquisitions; the marketer's mistaken belief that anything can be sold that can be produced; emphasis on information, accounting and control systems which isolate top management from the realities of the shop floor; and overemphasis on short-term cost reduction at the expense of long-term capital investment in new product and process technology and in human capital.

As in much of the recent literature on the ills of American management, Japanese-style management of production is often held up as the superior role model (Hayes, 1983). In particular, two features of Japanese production techniques — "just-in-time" or JIT inventory control and "quality circles" — have received widespread attention. It is important to emphasize, however, that these two techniques per se are not important determinants of the success of Japanese firms in reducing costs and increasing quality (Hayes, 1983). Rather, it is their overall approach to management in general and to production and operations management in particular that allows them to use these techniques and makes them effective. If the whole cannot be duplicated in substantial measure, imitation of any of the individual parts will not lead to the expected results (see Wood, Hull and Azumi, 1983, and Schonberger and Gilbert, 1983). The question then is not whether North American firms could or

should adopt "just-in-time" inventory or "quality circles," but whether they can or should adopt substantial elements of the total Japanese approach to strategy and management — focussing on a narrower range of products; competing globally; integrating marketing, R&D and production; reducing the emphasis on DCF as an investment decision criterion; and investing more heavily in human capital development within the firm. Hayes (1983) concludes that Japan's superior production performance is not based on advanced technology such as robotics or highly sophisticated production techniques such as "just-in-time" inventory or "quality circles," but rather on using standard technology and standard management techniques, but using them to their full potential. This conclusion is echoed by Saipe and Schonberger (1984):

> Just-in-Time is, first and foremost, an overall productivity and performance improvement program. In the long run, JIT causes an increase in labor productivity. . . . Companies that start up a JIT effort should not justify it on the promise of immediate reductions in direct labor. (p. 61)

Saipe and Schonberger are optimistic about the willingness and ability of North American firms to implement JIT production.

> Just-in-Time production is receiving unusually wide acceptance quite quickly. The companies which have begun to apply JIT principles are reporting quite compelling results. . . . A second reason for the widespread acceptance of JIT is that it is based upon manufacturing fundamentals. . . . JIT production is no longer an oriental mystery, but today is a North American phenomenon. (pp. 65–66)

American managers often see a trade-off between cost and quality — the higher the production cost, the higher the quality, and vice versa. At a given level of technology and organizational design this may be true, and the Japanese recognize that quality costs. Hayes (1983) quotes a Japanese scholar:

> If you do an economic analysis, you will usually find that it is advantageous to reduce your defect rate from 10 percent to 5 percent. If you repeat the analysis, it may or may not make sense to reduce it even further to 1 percent. The Japanese, however, will reduce it. Having accomplished this they will attempt to reduce it to 0.1 percent. And then to 0.01 percent. You might claim that this obsession is costly, that it makes no economic sense. They are heedless. They will not be satisfied with less than perfection. (p. 61)

This "uneconomic obsession" with quality may have two consequences that make it a less costly and hence more viable strategy.

- The drive for quality or "error-free operations" (Hayes, 1983, p. 62) may have increased productivity as a by-product. As Robert Lynas, group vice-president at TRW, notes, "a 2 percent reduction in defects is usually accompanied by a 10 percent increase in productivity" (cited in Hayes, 1983, p. 63).

- The cost of defect reduction may be offset by an increase in user satisfaction which spills over into increased demand and higher prices.

American firms tend to balance the cost of reducing defective products with the cost of replacing defective products once the defect has been identified, often by the customer. But one defect in a thousand may translate into thousands of dissatisfied customers who not only switch to other producers but also "disadvertise" the offending firm's products. Because the production, marketing and corporate strategy functions of American firms tend to be compartmentalized, costs other than production costs may not be factored into production decisions concerning the optimal defect rate. For example, Honda initially used low price to penetrate the U.S. market for motorcycles and automobiles. Over time, Honda built up a reputation for high quality. When it introduced lawn mowers, outboard motors, pumps, and so on in North America, it charged (and received) premium prices based on its reputation for quality in cars and motorcycles.

There are several major barriers that U.S. firms must overcome if they are to improve the quality of their products. Quality cannot be an add-on to the production process, but must be an integral part from design to production to after-sales service. Tsurumi (1982, p. 92) reports that U.S. automobile manufacturers have one quality inspector per seven workers to catch defects after they occur; Japanese firms have one per thirty workers, since each worker is his own quality control inspector. U.S.– style quality control has direct costs; Japanese-style does not seem to. In the automobile industry, for example, quality comes from personnel policies (absenteeism is three times higher and employee turnover is eight times higher for U.S. auto firms than Japanese ones); supplier policy (U.S. firms have ten times as many suppliers); "just-in-time" inventories which highlight quality problems (inventory/sales ratios are ten times higher for U.S. firms); and design (quality is engineered into Japanese cars). In Japan quality is *the* essential part of the system; in general in North America as yet it is not.

The narrower product line of most Japanese firms allows them to operate "focused factories" (Skinner, 1983b) in which they can devote their attention to the quality, cost and design of a few related products produced at high volumes. The wider range of products in most American factories diffuses worker and management attention away from quality and efficiency, raises production and inventory costs, and — most ironically — reduces the rate of product modification and improvement. Takamiya (1981) found that for comparable subsidiaries of Japanese and American firms operating in Britain, the Japanese had fewer models of any one product but their products tended to be newer, if no more technologically sophisticated, than those in the American subsidi-

aries. Hence, product innovation may not necessarily be in conflict with production efficiency (contrary to the conclusions of Lawrence and Dyer, 1983).

Certainly, over the past decade, the American and international markets have delivered a strong message to U.S. manufacturers that quality, cost and performance are valued by consumers at home and abroad. This message seems to be getting across to American firms and their managers, as shown by the increased levels of investment and R&D, the increased prominence of the production function in management, and the changes in organizational structure and locus of production decision making in U.S. firms (Meal, 1984). Peters and Waterman (1982) found that "excellent" American firms had business practices which were similar to those in "typical" Japanese firms. Peters and Waterman also concluded that American firms can and have reformulated their operations under pressure from poor performance and adverse conditions. The greater danger to further and more widespread improvement lies in the increasingly protectionist United States, in policies that act to insulate U.S. firms in some industries from the pressures to change.

The conclusions of this analysis have several implications for Canadian firms. Most importantly, the costs of the wide range of products typically produced by Canadian plants may go beyond low technical efficiency through loss of economies of scale into lower innovation, lower quality and higher defect rates. This conclusion reinforces the urgency of the need to rationalize production in Canada by reducing the number of products produced by each plant. On the positive side, however, the experience of Japanese firms would seem to show that a firm does not need to produce across the whole range of products — to be a full-line producer — in order to compete in markets for differentiated products; product excellence would often seem to be a superior strategy to product diversity. Canadian firms have begun to adopt JIT and Japanese-style quality control, if at a slower pace than American firms (Saipe and Schonberer, 1984; McMillan, 1984). The spread of these techniques has been hindered by the product diversity at the plant level in Canada.

Marketing

Two major shortfalls have been identified in American marketing management:

- a failure to realize that for many products the market is a global one and that a focus on national or even international markets from a national perspective will lead to a competitive disadvantage (see Levitt, 1984, and Hout, Porter and Rudden, 1983); and
- a failure to link marketing strategy into production strategy (see Hayes and Wheelwright, 1983, and Shapiro, 1983) or to develop and produce products oriented toward consumer needs.

The global trends of rapid technology diffusion, homogenization of incomes and tastes, and falling trade barriers have compressed the product life cycle (Phalla and Yusteh, 1976; Vernon, 1979). If firms in the United States develop and introduce products for only the U.S. market or for a sequence of markets starting with the U.S. market, they may find that their U.S. market share is eroded by products from abroad or that by the time they turn to overseas markets to introduce their products, their competitors are already firmly entrenched. Instead they have had to increasingly globalize their perspective and see market opportunities for new products in countries abroad as well (Watson, 1983). Without this perspetive, U.S. firms will increasingly find their markets abroad pre-empted and their markets at home threatened.

Again, market forces — in this case international market forces — are motivating U.S. firms to reorient toward global markets. The export share of GNP in the United States doubled between 1970 and 1980, as did the import share of domestic consumption. Over the 1980–84 period, however, appreciation of the U.S. dollar by over 40 percent led to a worsening trade deficit and a reduced ability of U.S. firms with products manufactured in the United States to compete abroad or to retain market share in the United States.

Canadian firms in the manufacturing sector tend to be nationally rather than internationally — much less globally — oriented.[13] In addition, they tend to produce products in the mature stage of the product life cycle. As that life cycle is compressed, they have much less room to manoeuvre. In response, they will have to follow some combination of reducing costs through product rationalization, investing in R&D or licensing to move toward the first stage of the cycle, or investing abroad to take advantage of the comparative advantage of global production.

Human Capital

As part of the re-emphasis on production, there is renewed concern over "people management," training, and development within American firms. Human resource management has become a hot topic in management education. Reich (1983), Magaziner and Reich (1982), Abernathy et al. (1983a, 1983b), and Lawrence and Dyer (1983) conclude that the hierarchical, bureaucratic nature of management in large American firms has led to rigidity in response to change, separation between workers and managers, and a concentration on the paperwork of "scientific management" as an end in itself.

The ratio of non-production workers to production workers in American industry increased from 18 percent in 1950 to 30 percent in 1980. The increase in the ratio of management to production workers may have led to increased worker alienation, more strikes, and lower productivity (Gordon, 1981; Bowles et al. 1983). Maki (1983) finds a strong relationship between organizational overhead, strike activity, and low productivity

growth both among countries and among industries in a given country. Prais (1981) finds a correlation between strike proneness and plant size in British industry, and attributes this to the reationship between plant size and the supervisor/ supervisee ratio, and to the separation of production workers and management. Greenburg and Glaser (1980) conclude:

> A climate and structure [are needed] that differs from the traditional hierarchical organization. It calls for an open style of management, such that information is shared and challenges or suggestions are genuinely encouraged. (p. 3)

O'Toole (1981) goes further:

> The root causes of low productivity and declining innovation are to be found in our culture, and not in our economic policies. . . . Only changes in the philosophy and organization of work can overcome America's economic decline. . . . [Workers need] conditions of diversity, flexibility, choice, mobility, participation, security, and rights tied to responsibilities . . . conditions that would go a long way towards making America work again. (pp. 184, 187)

Reich (1983) shares those concerns. He concludes that parallel hierarchical bureaucracies have grown up in business and government that inherently lead to specialization, rigidity, resistance to change, and isolation and economic competition experienced by those at the bottom. Reich's conclusion is severe:

> America has a choice: it can adapt itself to the new economic realities by altering its organization, or it can fail to adapt and thereby continue its present economic decline. Adaptation will be difficult. . . . To change the way we conduct our business and our government implies a more general change of customs, attitudes, and values which are parts of our cultural heritage. . . . But failure to adapt will end the social fabric irreparably. Adaptation is America's challenge. It is America's new frontier. (p. 21)

Adaptation and a greater concern with human resource management have become a central focus in many American firms (Cantor, 1983), but the change has been slow and uneven and has often been met with stiff resistance. Simmons and Mares (1983), however, find improvement in management-worker-union relations through a wide variety of new forms of organization, control and, most importantly, in attitudes.

One of the strengths of Japanese firms is said to lie in their management of human resources. The lifetime employment practices and the company spirit of employees are often cited as major contributors to the success of Japanese firms. With lifetime employment, workers may be less resistant to changes in production technology which increase output per worker (since increased efficiency will not lead to layoffs), and the firm may be more willing to invest in worker-training and management development (since it will realize the full return on its investment in

human capital). Since pay and position in Japanese firms are closely related to seniority, employees have every incentive to remain with the firm over their working life and to work toward ensuring the survival of their firm. The company welfare system also promotes this concern.

In assessing the costs and benefits of the Japanese system and its applicability to American businesses, we must go beyond general stereotypes. First, lifetime employment is practised most widely in "first tier" Japanese firms, not on an economy-wide basis. Only about one-third of the workers in the Japanese industrial sector are employed in firms practising lifetime employment. Toyota has lifetime employment but its parts suppliers often do not. During an economic downturn, Toyota may source more parts in-house and push its employment problems back onto its suppliers, where lifetime employment is not the norm.

Second, Japanese workers typically retire at an earlier age than their American counterparts. Retired workers are rehired during boom periods, only to be laid off when demand slackens. A similar situation exists for women, with increased hiring during booms and layoffs during recessions.[14] Also, bonuses of three to four months' pay are given during boom times but withdrawn during recessions. This practice gives Japanese firms more flexibility in their cost structure over the business cycle.

Third, lifetime employment with one firm can come at a cost of reduced job and geographical mobility, often highly prized liberties for American workers.

Fourth, being a "company man" may impose severe costs on workers. Recently, several authors have been highly critical of the costs imposed by the Japanese management system on workers (see for example, Woronoff, 1983; Sethi et al., 1984; and Kamata, 1983). These range from a high degree of regimentation of all important aspects of life, loss of personal freedom, encouragement of group thinking and intolerance of individual needs and idiosyncracies, an education system largely oriented toward providing staffing for the major corporations accompanied by horrendous pressures on students to succeed. All is not roses (or cherry blossoms) for Japanese workers. There is also considerable doubt about whether the attitudes and values of Japanese workers could be transferred to North America, even if U.S. firms tried. As Kamata (1983) writes, "They're so docile and undoubting I could almost cry." After a honeymoon period, workers in several subsidiaries of Japanese firms in the United States have recently begun to express open dissatisfaction with the hard work and regimentation expected of them (Sethi et al., 1984).

These problems notwithstanding, Japanese management of human resources may have much to teach American managers (and North American professors of business administration). Certainly the outpouring of books on Japanese management would indicate interest in this

subject. More importantly, Japanese firms have generally been successful in transferring some of their management techniques, although with some adaptation to their subsidiaries in America and Europe (Amano, 1979; Johnson, 1977; and Takamiya, 1981). In a particularly interesting article, Takamiya (1981) compared the operations of two Japanese subsidiaries, an American subsidiary, and a British-owned firm in the colour TV industry in Britain. I quote from this article at length:

> A popular explanation [for Japanese performance] is that Japanese companies typically create a happy, loyal workforce. . . . This explanation is not necessarily convincing in that Japanese performance on production is overwhelmingly superior while their score on the human side is very similar to, or only marginally better than, American or British scores . . . . [Moreover] there is little correlation between worker satisfaction and organizational effectiveness. . . . It is apparent that on all these measures [wages, sick pay benefits, and holidays] Japanese companies provide much poorer incentives than British or American companies. . . . Furthermore, technologies used by Japanese companies are no more sophisticated than British and American. (p. 7)

Takamiya attributes the superior performance of the two Japanese firms to a narrower product line; design engineering for low cost, quality and dependability; constant individual feedback on quality; more flexible, less hierarchically or functionally differentiated jobs; strict discipline; more interdepartmental cooperation, coordination, interchange, and group decision making; and the use of one company-wide union. Most importantly:

> As in the case of production management, all these [management] instruments are of a rather primitive nature. They are not sophisticated managerial methods but rely heavily on people's attitudes and industriousness. The American company, in contrast, has highly developed standard communication procedures. (p. 10) While the American company tries to develop a "structure" which functions sufficiently well irrespective of the personalities and attitudes of the workforce, the Japanese approach is to train workers who can work effectively irrespective of structure. (p. 11) Supervisors seem to exercise much greater work pressures and discipline on workers. . . . Japanese MNEs rely heavily on the individual's internalization of a special attitude, perspective, and work philosophy. (p. 14)

With some modification, the Japanese managerial system would seem to be transferable abroad by Japanese firms, and American firms can and have adopted some of the specifics of the Japanese system. In particular, Weiss (1984) recommends that U.S. firms employ more engineers per worker and place their engineers in closer physical contact with production workers; employ more selective screening and training practices in hiring; and use steeper wage profiles and substantial pay differentials to give workers incentives to stay with the firm longer and work harder and

"smarter."[15] As stressed above, however, to be effective the Japanese system must be used as an integrated package: the whole is greater than the sum of the parts.

There is a growing recognition among American managers of a widespread, systematic failure to manage the work force effectively. Conversely, there seems to be a growing awareness among employees that their future is more closely tied to the future of the firms they work for than they had previously thought, and that wage increases cannot outstrip productivity increases in the long run (Simmons and Mares, 1983). Adaptability is a strength of the private enterprise system, and firms and workers have certainly been given a strong message that they must adapt to the new industrial competition or suffer dramatic declines in profits, wages and employment.

As a sign of recognition by both management and labour of the need to change, there have recently been several interesting developments in the relationship between the employees and equity owners of firms, as noted by Simmons and Mares (1983).

During the 1981–82 recession, several large unions gave substantial wage concessions to move wages more into line with those in competing industries abroad. Whether these concessions will continue as the economy recovers is an open and important question, especially in view of the substantial bonuses management granted themselves in some industries as recovery began.

There has been increased worker representation on boards of directors, often accompanied by wage concessions, and in some cases even employee ownership of firms. These initiatives are designed to give employees more say in running the firm and participating in its profits and losses. Similarly, several unions have used their pension funds to buy into companies, both to give them some measure of control and to help fund investment to increase productivity. This is not yet a frequent practice, however, partly because of union fears of placing all their eggs in one basket and their doubts about whether partial ownership will bring real change in employee-owner relationships beyond a lessening of union power to press its demands.

There have also been scattered instances in which the workers or managers have bought the firm or one of a firm's units outright. There are several reasons for employee buyout.

- If the parent firm has decided to close a plant, its workers may decide that they can run it better and make a profit. In some instances, corporate accounting systems or management practices have loaded heavy overhead charges onto individual plants. When these charges are removed, the plant becomes profitable.
- Workers may be willing to take substantial pay cuts in order to keep a plant open, but they will only take such cuts in return for total

ownership which allows them ultimately to reap the benefits brought about by their sacrifices.

- A firm may acquire a business through conglomerate mergers and lose money because it has no interest or expertise in the business. In order to regain part of its initial investment it can resell the business to its employees, management, or in some cases even the original owners. For example, W.R. Grace purchased one firm for $14 million only to sell it back to its original owner after ten years of unsuccessful operation — for $4 million.

In all these situations, the underlying factor in the buyout is a tacit admission that the parent firm had exceeded the limits at which it could operate its internal markets more efficiently than the external market — proving that the sum of the parts is worth more than the whole. This is a healthy trend in American business since it shows how the dynamics of the market interact with the internal market of the firm to motivate a more efficient allocation of resources. In the future, more of these innovative arrangements are to be expected as American businesses adjust to the new international competition.

Drucker (1976) estimates that 50 to 60 percent of the equity capital of American business in 1975 was owned by employees through their pension funds. He projects this to rise to 66 percent of the equity and 40 percent of the debt capital by 1990. Drucker writes that by 1975 the largest employee pension funds, those of the 1,000 to 1,300 biggest firms plus the 35 industry-wide funds, together already owned over 50 percent of each of the 1,000 largest American corporations. Drucker concludes that there is considerable potential for unions to band together to exercise control over the management of many of these large corporations.

The conclusions of this analysis have several implications for firms in Canada, where there is a greater polarization between production workers and management than in the United States. Unions are more militant, ideological and political; and managers tend to be more elitist, less flexible and more concerned with the prerogatives of management. Relations between unions and management in Canada tend to be more confrontational than in the United States, with both sides more intent on scoring points and maintaining their positions than in working toward a cooperative solution. During the recession of 1980–82, there were fewer union "give backs" in Canada than in the United States and fewer employee bailouts and buyouts.[16]

This situation is unfortunate since mutual understanding and some measure of trust and cooperation will be essential components in improving the performance of Canadian firms and the Canadian economy in a period of rapid change. Yet, as McMillan (1984) shows in a comparison of Japanese and Canadian personnel policies, there is much

that Canadian managers can learn from Japanese management techniques and successfully apply in the Canadian context.

Summary

Three central questions are addressed in the recent literature on the strategic response of American firms to the "new industrial competition." Are there problems with American corporate management? What are the causes of these problems? How can corporations best respond to these problems? As this brief review of the literature has indicated, there is no shortage of answers to all of these questions.

There is a general consensus that American firms have not been performing well either relative to their performance in the postwar period through the late 1960s or relative to some firms in Europe and Japan. Here the consensus ends, however. The causes of this relative decline which have been identified include problems in the management of all the functional areas of business — finance, production, marketing, accounting and control, organizational structure, and human resources management — and in overall corporate management and strategy.

The corporatist prescriptions of these authors generally seem to rely on the market as it is currently structured to induce American corporations to make the changes in operations in line with their recommendations. The large number of corporations which have reorganized, restructured and turned around their operating and overall business strategies would lend support to this view. On the other hand, studies that show the general benefits of "paper entrepreneurialism" as measured by stockholder returns (Jensen and Ruback, 1983), seem to indicate that this "problem" — if it is a problem — will not go away unless there is a restructuring of financial markets (Bower, 1983), the taxation system, and the maze of government regulations under which business must operate. These conditions are unlikely to change radically or rapidly in the near future.

The proponents of a government corporatist approach, such as Reich (1983), advocate a government industrial policy to act as an agent of change and a regulator in the markets for capital, labour and R&D, to prod firms and workers to restructure and to grease the wheels of change. The advocates of radical change in the economic relationships of workers, managers and stockholders are even more vague about how their proposed changes will come about. Gordon, Weisskopf and Bowles (1983, p. 157) conclude that "non-reproductive cycles" (times of low investment and productivity growth such as occurred during 1973–79) lead to crises (1980–82) which lead to "intensified class conflict and sharp debates over major economic policy issues." These eras of conflict are times of intensive institutional innovation.

If these analyses show nothing else, they depict a period of intense turbulence, change, threat and opportunity for American corporations and for the American economy. How American corporations will and should change to meet these threats and seize these opportunities is as yet unclear. What is clear, however, is that the market system is working reasonably well in the United States to reallocate resources from one industry to another and force firms to improve their operations, given current government macroeconmic policies and its current intervention in the market system. The biggest danger to the competitive ability of American firms is U.S. government macroeconomic policies which depress savings and investment, encourage budget deficits and lead to an inflated exchange rate and to actions aimed at sheltering regions, firms and workers from competititive pressures. Within the parameters set by this situation, however, there would seem to be substantial room for improvement of the operations and strategies of American firms.

Adapting to change is often held out as one of the great strengths of firms within the free enterprise, capitalist market system. Any initiative that promotes adaptation to change and increases the ability of firms to adapt to change should benefit the economic efficiency and economic welfare. Conversely, initiatives that impede change and reduce the ability of firms to respond to change will reduce economic welfare.

At the level of analysis, these conclusions are truisms among economists. It is at the level of implementation that severe problems have arisen for government policy and implementation by firms. Action is particularly difficult under the current conditions of slow or no growth when the attention of government and business is largely devoted to short-term firefighting rather than addressing the long-term problems which have caused the fires. This myopia is understandable and it would be unreasonable and dysfunctional to act as if it can be significantly altered unless there is a substantial long-run improvement in the American economy.

Restructuring may be difficult. It can entail a major reorientation of the values, attitudes and methods of management, as well as investment in R&D, capital equipment and export marketing. Moreover, previously sheltered groups will often find their incomes reduced in a more competitive environment. These problems are compounded for large firms, which have developed considerable organizational inertia and resistance to change.

Throughout this paper, the underlying theme is the failure of management in America to respond to the new industrial competition. Yet North America, particularly the United States, has the highest level of formal management education in the world. There would seem to have been a massive failure of our business schools to identify the crucial issues of management, to formulate the requirements for effective management, and to disseminate these insights to management through business

education, management training, and publications. Yet several of the researchers on Japanese management (cited above) conclude that this success lies not in the unique cultural characteristics of the Japanese or in some fundamental breakthrough in management theory or practice. Rather, the success of Japanese management is largely based on applying management fundamentals long known to North American managers and taught at North American business schools for decades. Their secret is to apply these fundamentals consistently, rigorously and intensively. If this is indeed the case, then there is considerable potential for North American firms to respond successfully to the Japanese challenge.

There have been several developments in response to the problems of North American business. Courses in production, R&D management, international business, and human resource management have begun to receive more emphasis in business schools. Courses and segments on Japanese management have also been incorporated into business school courses and executive development seminars and programs. These responses follow the typical North American practice of separating management education, development and training from day-to-day business operations. Japanese firms, by contrast, incorporate their training programs of all levels from the shop floor to the executive suite as an integral part of the firm's ongoing business operations.

At present in Canada, the government heavily subsidizes business education and worker training programs (as part of its subsidies to all post-secondary education) if they are held within a formal academic setting such as a business school and community college. This procedure largely directs management development and worker training at new entrants into the labour force. In-house management development and worker training are only aided to the extent these expenses are tax deductible. Such programs are the only means by which the skills of the stock of existing employees can be upgraded. At present, there seems to be a need for further development of management and worker skills of not only new labour force entrants but, as importantly, those already employed at all levels of the firm. Business schools in Canada already run a wide variety of management programs and large firms run others in-house. These are on a "full cost" basis, whereas management courses leading to MBA, HBA, and B. Comm. degrees are highly subsidized. One possible way to assist management training in Canada would be to extend some form of subsidy to these management development programs to further subsidize worker retraining programs. It is interesting that government subsidizes 85 percent of the tuition cost for a candidate in a program leading to an MBA degree, but that individuals and firms must pay for the entire cost of executive development programs (aside from possible reductions in their tax liabilities) in-house or at privately owned training schools.

This conclusion is reinforced when the characteristics of Canadian management are considered. Daly (1980) reports that on average Canadian managers have had less formal education than those in the United States and, in particular, there are far lower percentages of Canadian managers with formal business and engineering education. Canadian managers tend to be promoted more on the basis of seniority and personal connections and less on ability, education and performance than is the case in the United States. Not surprisingly, Canadian managers have been found to be more rigid, hierarchical and conservative (and socially homogeneous), less willing to take risks, make innovations, adapt to change, or even recognize that change is necessary. They are less likely to use sound management fundamentals in finance, production, human resource management, marketing and international business, and more prone to manage on the basis of the received doctrine of their corporate culture. At best, new entrants into management trained in business schools can only influence management practices in Canada in the long run, provided that their skills have not atrophied and their initiative not been stultified by the long years they must first put in working their way up the corporate ladder. (Even these new managers with formal business training are relatively few in number, compared with the situation in the United States.) Programs aimed at the existing stock of practising middle and upper level managers are needed if the necessary substantial change in managerial performance is to be achieved.

In addition to increasing assistance to management and worker development programs, it would be beneficial to set up a national management council composed of representatives from business, labour and government (and a few business academics) to provide funding for business research and to guide that research into areas of direct relevance to important current business problems.[17] Funds could also be allocated to the Canadian Labour Market and Productivity Centre and to the Social Science and Humanities Research Council to pursue research under such a mandate. Funds could also be provided for doctoral students in business, since Canada currently produces only 1 percent of the Ph.Ds in business in North America, and Canadian business schools have severe staffing problems in several disciplines.

As Hayes (1983), Takimiya (1981), and Abernathy et al. (1983a) conclude, Japanese firms have been successful not through using super-high technological hardware or super-sophisticated management systems, but in applying basic management principles well. North American management has often failed to apply to these principles and North American business schools have failed to teach them adequately. Change is occurring, but it could be accelerated with appropriate government incentives for management research, education, and worker and management training.

Notes

This paper was completed in November 1984.

1. Other critics of U.S. economic performance have cited inappropriate U.S. macroeconomic, trade and industrial policies as causes for this perceived poor performance. See Lecraw (1984b) for a survey of this literature.
2. A story relates how a Frenchman, a Japanese and an American about to be executed were asked for their final request. The Frenchman asked for a glass of wine and a cigarette; the Japanese asked to give a speech on the glories of Japanese management; the American asked to be executed first because he couldn't stand to hear another speech on Japanese management.
3. Levitt (1984) concludes that this process of expanding to take in world markets spells the death knell for U.S.– based multinational organizations.
4. However, Charette, Kaufman, and Henry (1985), in a paper for this Royal Commission, find that Japanese firms exhibited a lesser propensity for "labour hoarding" over the business cycle than did U.S. firms.
5. Similarly, Donaldson and Lorsch (1983) conclude that diversification through mergers and acquisitions was motivated by a drive to reduce the firm's dependence on any one product market in order to ensure its long-run survival.
6. It is ironic that some of the harshest critics of conglomerate firms, including Reich, are also the ones who advocate a U.S. industrial policy in which the entire economy would be run like a huge conglomerate.
7. Lecraw and Thompson (1978) replicate this study for firms in Canada, with similar results.
8. See also Rumelt (1982) and Montgomery and Christensen (1983) on the determinants and effects of different diversification strategies.
9. Based on a conversation (August 1984) with Robert Hayes.
10. Pike (1984), in a study of 144 large firms in Britain, finds a significant negative association between the level of capital budgeting sophistication and corporate performance.
11. In a PBS television interview of Robert Hayes, May 9, 1984.
12. According to Professor James Hatch, School of Business Administration, University of Western Ontario, author of *Investment Management in Canada* (Toronto: Prentice Hall, 1982).
13. According to Professor Harold Crookell, School of Business Administration, University of Western Ontario, principal author of the *Hatch Report* on Canada's trade problems and prospects.
14. In fact, unemployed women and "temporary," often older, workers are not even counted in Japan's unemployment statistics. Female/male salary ratios are 53 percent in Japan, compared with 67 percent in the United States and 97 percent in Sweden.
15. In his comparisons of U.S. and Japanese electronics firms, Weiss (1984) finds lower absenteeism and quit rates at Western Electric compared with three large Japanese firms.
16. According to Professor David Peach, School of Business Administration, University of Western Ontario, co-author of *The Practice of Industrial Relations*, rev. ed. (Toronto: McGraw-Hill Ryerson, 1984).
17. It is difficult to see the relevance now or in the future of most of the current academic research on business as published in such journals as *Journal of Finance, Operations Research, Management Science*, and so on, (Teece and Winter, 1984; Harris, 1984; and Rehder, 1982).

Bibliography

Abernathy, William J. 1978. *The Productivity Dilemma*. Baltimore. Johns Hopkins University Press.

Abernathy, William J., Kim B. Clark, and Alan M. Kantrow. 1983a. "The New Industrial Competition." *Harvard Business Review* 59 (5). Reprinted in *Survival Strategies for American Industries*, edited by Alan Kantrow. New York: John Wiley and Sons.

________. 1983b. *Industrial Renaissance*. New York: Basic Books.

Amano, Matt A. "Organizational Changes of a Japanese Firm in America." *California Management Review* (Spring).

Baldwin, J., and P. Gorecki. 1985. "The Relationship between Trade and Tariff Patterns and the Efficiency of the Canadian Manufacturing Sector in the 1970s: A Survey." In *Canada–United States Free Trade*, volume 11 of the research studies prepared for the Royal Commission on the Economic Union and Development Prospects for Canada. Toronto: University of Toronto Press.

Bishop, Paul M., and Harold Crookell. 1985. "Specialization and Foreign Investment in Canada." In *Canadian Industry in Transition*, volume 2 of the research studies prepared for the Royal Commission on the Economic Union and Development Prospects for Canada. Toronto: University of Toronto Press.

Bower, Joseph L. 1983. *The Two Faces of Management*. Boston: Houghton Mifflin.

Bowles, Samuel, David Gordon, and Thomas Weisskopf. 1983. *Beyond the Wasteland*. New York: Doubleday.

Bradford, David L., and Allan R. Cohen. 1984. *Managing for Excellence*. New York: John Wiley and Sons.

Buzzell, Robert D., and Frederik D. Wiersema. 1981. "Modelling Changes in Market Share: A Cross-Sectional Analysis." *Strategic Management Journal* 2 (1).

Canada. Royal Commission on Corporate Concentration. 1978. *Report*. Ottawa: Minister of Supply and Services Canada.

Charette, Michael, Robert R. Henry, and Barry Kaufman. 1985. "The Evaluation of the Canadian Industrial Structure: An International Perspective." In *Canadian Industry in Transition*, volume 2 of the research studies prepared for the Royal Commission on the Economic Union and Development Prospects for Canada. Toronto: University of Toronto Press.

Cisiel, David H., and Richard D. Evans. 1984. "Returns to Corporate Diversifiation in the 1970s." *Managerial and Decision Economics* (June).

Clee, Gilbert, and Alfred di Supio. 1983. "Creating a World Enterprise." In *Managing Effectively in the Global Marketplace*, edited by Douglas Dickson. New York: John Wiley and Sons.

Crookell, Harold, and Paul Bishop. 1983. "Specialization and Foreign Investment in Canada." Paper prepared for the Department of Finance, October. Ottawa: The Department.

Daly, Don H.J. 1980. "Canadian Management: Past Recruitment Practices and Future Training Needs." In *Highlights and Background Studies*, edited by Max Von Zur-Muehlen. Ottawa: Canadian Federation of Deans of Management and Administrative Studies.

________. 1983. *Canada in an Uncertain World Environment*. Montreal: The Institute for Research on Public Policy.

________. 1985. "Rationalization and Specialization in Canadian Manufaturing." In *Canadian Industry in Transition*, volume 2 of the research studies prepared for the Royal Commission on the Economic Union and Development Prospects for Canada. Toronto: University of Toronto Press.

Davidson, William H., and Philippe Haspeslagh. 1983. "Shaping a Global Product Organization." In *Managing Effectively in the Global Marketplace*, edited by Douglas Dickson. New York: John Wiley and Sons.

Dickson, Douglas, ed. 1983. *Managing Effectively in the Global Marketplace*. New York: John Wiley and Sons.

Donaldson, Gordon. 1984. *Managing Corporate Wealth*. New York: Praeger.

Donaldson, Gordon, and Jay W. Lorsch. 1983. *Decision Making at the Top*. New York: Basic Books.

Drucker, Peter, E. 1976. *The Unseen Revolution: How Pension Fund Socialism Came to America*. New York: Harper and Row.

Ellsworth, Richard R. 1983. "Subordinate Financial Policy to Corporate Strategy." *Harvard Business Review*.

Fallows, James. 1980. "American Industry: What Ails It, How to Save It." *Atlantic Monthly* (September).

Franko, Lawrence F. 1978. "Muiltinationals: The End of U.S. Dominance." *Harvard Business Review* 56 (6).

Gordon, David M. 1981 "Capital-Labour Conflict and the Productivity Slowdown." *American Economic Review, Papers and Proceedings* 71 (2): 30–35.

Gordon, David M., Thomas E. Weisskopf, and Samuel Bowles. 1983. "Long Swings and the Non-reproductive Cycle." *American Economic Review Papers and Proceedings* (May).

Greenberg, Paul D., and Edward M. Glaser. 1980. *Some Issues in Joint Union-Management Quality of Worklife Improvement Efforts*. Kalamazoo, Mich.: E.W. Upjohn Institute for Employment Research.

Hall, William K. 1983. "Survival Strategies in a Hostile Environment." In *Survival Strategies for American Industries*, edited by Alan Kantrow. New York: John Wiley and Sons.

Hamermesh, Richard C., and Roderick E. White. 1984. "Manage Beyond Portfolio Analysis." *Harvard Business Review* (January–February).

Harrigan, Kathryn Rudie. 1980. "The Effect of Exit Barriers Upon Strategic Flexibility." *Strategic Management Journal*.

Harrigan, Kathryn, and Michael E. Porter. 1983. "End-Game Strategies for Declining Industries." In *Managing Effectively in the Global Marketplace*, edited by Douglas Dickson. New York: John Wiley and Sons.

Harris, Robert G. 1984. "The Values of Economic Theory in Management Education." *American Economic Review* (May).

Hatch, James, Larry Wynant, and Mary Jane Grant. 1983. "Federal Lending Programs for Small Business: No Longer Needed?" *Canadian Public Policy* (September).

Hayes, Robert H. 1983. "Why Japanese Factories Work." In *Survival Strategies for American Industries*, edited by Alan Kantrow. New York: John Wiley and Sons.

Hayes, Robert, H., and William Abernathy. 1980. "Managing Our Way to Economic Decline." *Harvard Business Review* 58 (4). Reprinted in *Survival Strategies for American Industries*, edited by Alan Kantrow. New York: John Wiley and Sons.

Hayes, Robert, H., and David D. Garvin. 1983. "Managing As If Tomorrow Mattered." In *Survival Strategies for American Industries*, edited by Alan Kantrow. New York: John Wiley and Sons.

Hayes, Robert, H., and Steven C. Wheelwright. 1983. "Link Manufacturing Process and Product Life Cycles." In *Survival Strategies for American Industries*, edited by Alan Kantrow. New York: John Wiley and Sons.

Hill, C.W.L. 1983. "Conglomerate Performance over the Cycle." *Journal of Industrial Economics* (December).

Hout, Thomas, Michael Porter, and Eileen Rudden. 1983. "How Global Companies Win Out." In *Managing Effectively in the Global Marketplace*, edited by Douglas Dickson. New York: John Wiley and Sons.

Jensen, Michael C., and Richard S. Ruback. 1983. "The Market for Corporate Control: The Scientific Evidence." *Journal of Financial Economics* (April).

Johnson, R.T., 1977. "Success and Failure of Japanese Subsidiaries in America." *Columbia Journal of World Business* (Spring).

Kamata, Satoshi. 1983. *Japan in the Passing Lane*. New York: Pantheon.

Kanter, Rosabeth Moss. 1983. *The Change Masters*. New York: Simon and Schuster.

Kantrow, Alan, ed. 1983. *Survival Strategies for American Industries*. New York: John Wiley and Sons.

Krugman, Paul. 1984. "Targeted Industrial Policies: Theory and Evidence." In *Industrial Change and Public Policy*, edited by the Federal Reserve Bank of Kansas City. Kansas City: Federal Reserve Bank.

Lawrence, Paul R., and David Dyer. 1983. *Renewing American Industry*. New York: The Free Press/Macmillan.

Lecraw, D.J. 1984a. "Diversification Strategy and Economic Performance." *Journal of Industrial Economics* (December).

Lecraw, Donald. 1984b. "Industrial Policy in the United States: A Survey." In *Economics of Industrial Policy and Strategy*, volume 5 of the research studies prepared for the Royal Commission on the Economic Union and Development Prospects for Canada. Toronto: University of Toronto Press.

Lecraw, Donald, and D. N. Thompson. 1978. *Conglomerate Mergers in Canada*. Ottawa: Minister of Supply and Services Canada.

Levitt, Theodore. 1984. *The Marketing Imagination*. New York: Free Press.

Linn, Scott C., and John J. McConnell. 1983. "An Empirical Investigation of the Impact of Anti-Takeover Amendments of Common Stock Prices." *Journal of Financial Economics* (April).

Lodge, George C. 1983. *The American Disease*. New York: Alfred A. Knopf.

Magaziner, Ira, and Robert Reich. 1982. *Minding America's Business*. New York: Harcourt Brace Jovanovich.

Maki, Dennis R. 1983. "Strike Activity and Productivity Growth." *Columbia Journal of World Business* (Summer).

Malatesta, Paul H. 1983. "The Wealth Effect of Merger Activity and the Objective Functions of Merging Firms." *Journal of Financial Economics* (April).

Mansfield, Edwin. 1985. "Technological Change and the International Diffusion of Technology: A Survey." In *Technological Change in Canadian Industry*, volume 3 of the research studies prepared for the Royal Commission on the Economic Union and Development Prospects for Canada. Toronto: University of Toronto Press.

Mason, R.H., and M.B. Goudzwaard. 1976. "Performance of Conglomerate Firms: A Portfolio Approach." *Journal of Finance* (March).

Matthews, R.C.O., ed. 1982. *Slower Growth in the Western World*. London: Heinemann.

McMillan, Charles. 1984. *The Japanese Industrial System*. Berlin: de Gruyter.

Meal, Harlan, C. 1984. "Putting Production Decisions Where They Belong." *Harvard Business Review* (March–April).

Millar, William B. 1984. *America's Management Challenge: Capitalizing on Change*. Radnor, Penn.: Chilton Book.

Montgomery, Cynthia A., and H.K. Christensen. 1981. "Corporate Economic Performance: Diversification Strategy versus Market Structure." *Strategic Management Journal* 2 (4).

Myers, Stewart C. 1984. "Finance Theory and Financial Strategy." *Interfaces* (January–February).

O'Toole, James. 1981. *Making America Work: Productivity and Responsibility*. New York: Continuum.

Ouchi, William C. 1981. *Theory Z: How American Business Can Meet the Japanese Challenge*. Reading, Mass.: Addison-Wesley.

________. 1984. *The M-Form Society*. Reading, Mass.: Addison-Wesley.

Pascale, R.T. 1978. "Personnel Practices and Employee Attitudes: A Study of Japanese and American Managed Firms in the United States." *Human Relations* 31 (7).

Pascale, Richard Tanner, and Anthony G. Athos. 1981. *The Art of Japanese Management*. New York: Simon and Schuster.

Peters, Thomas J., and Robert H. Waterman. 1982. *In Search of Excellence*. New York: Harper and Row.

Phalla, Nariman K., and Sonia Yuspeh. 1976. "Forget the Product Life Cycle Concept." *Harvard Business Review* (January–February).

Pike, R.H. 1984. "Sophisticated Capital Budgeting Systems and Their Association with Corporate Performance." *Managerial and Decision Economics* (June).

Porter, Michael E. 1976. "Please Note Location of Nearest Exit: Exit Barriers and Planning." *California Management Review* (Winter).

———. 1980. *Competitive Strategy*. New York: Free Press.

———. 1985. *Competitive Advantage*. New York: Free Press.

Prais, S.J. 1981. *Productivity and Industrial Structure: A Statistical Study of Manufacturing Industry in Britain, Germany, and the United States*. New York: Cambridge University Press.

Rehder, Robert B. 1982. "American Business Education: Is It Too Late to Change?" *Sloan Management Review* (Winter).

Reich, Robert B. 1983. *The Next American Frontier*. New York: Times Books.

Rumelt, Richard P. 1982. "Diversification Strategy and Profitability." *Strategic Management Journal* 3.

Saipe, Alan L., and Richard J. Schonberger. 1984. "Don't Ignore Just-in-Time Production." *Business Quarterly* (Spring).

Salter, Malcolm, and Wolf Weinhold. 1982 "What Lies Ahead for Merger Activity in the 1980s." *Journal of Business Strategy* (Spring).

Schein, Edgar H. 1981. "SMR Forum: Does Japanese Management Style Have a Message for American Managers?" *Sloan Management Review* (Fall).

Schlossstein, Steven. 1984. *Trade War*. New York: Congdon Weed.

Schoeffler, Sidney. 1984. "Impact of Strategic Planning on Profit Performance." *Harvard Business Review* (March/April).

Schonberger, Richard, and James Gilbert. 1983. "Just-in-Time Purchasing: A Challenge for U.S. Industry." *California Management Review* (Fall).

Scott, Bruce R. 1984. "National Strategy for Stronger U.S. Competitiveness." *Harvard Business Review* (March–April).

Sethi, R., N. Namiki, and C.L. Swanson. 1984. *The False Promises of the Japanese Miracle: Illusions and Realities of the Japanese Management System*. Marshfield, Mass.: Pitman Publishing.

Shapiro, Benson P. 1983. "Can Marketing and Manufacturing Coexist?" In *Survival Strategies for American Industries*, edited by Alan Kantrow. New York: John Wiley and Sons.

Shetty, Y.K. 1982. "Management's Role in Declining Productivity." *California Management Review* (Fall).

Simmons, John, and William Mares. 1983. *Working Together*. New York: Alfred A. Knopf.

Skinner, Wickham. 1983a. "Manufacturing: The Missing Link in Corporate Strategy." In *Survival Strategies for American Industries*, edited by Alan Kantrow. New York: John Wiley and Sons.

———. 1983b. "The Focused Factory." In *Survival Strategies for American Industries*, edited by Alan Kantrow. New York: John Wiley and Sons.

———. 1984. "Operations Technology: Blind Spot in Strategic Management." *Interfaces* (January–February).

Smiley, Robert H., and S. Abraham Ravid. 1983. "The Importance of Being First." *Quarterly Journal of Economics* (May).

Song, Jae H. 1983. "Diversifying Acquisitions and Financial Relationships: Testing 1974–76 Behaviour." *Strategic Management Journal* 4 (2).

Takamiya, Makoto. 1981. "Japanese Multinationals in Europe: Internal Operations and their Public Implications." *Columbia Journal of World Business* (Summer).

Takeuchi, Hirotaka. 1981. "Productivity: Learning from the Japanese." *California Management Review* (Summer).

Teece, David J., and Sidney G. Winter. 1984. "The Limits of Neoclassical Theory in Management Education." *American Economic Review* (May).

Thurow, Lester. 1980. *The Zero Sum Society*. New York: Basic Books.

_________. 1983. "The Political Realities of Industrial Policy." *Harvard Business Review* (September–October).

Tsurumi, Yoshi. 1982. "Japan's Challenge to the U.S.: Industrial Policies and Corporate Strategies." *Columbia Journal of World Business* (Summer).

Vernon, Raymond. 1966. "International Investment and International Trade in the Product Cycle." *Quarterly Journal of Economics* (May).

_________. 1971. *Sovereignty at Bay*. New York: Basic Books.

_________. 1979. "The Product Cycle Hypothesis in a New International Environment." *Oxford Bulletin of Economics and Statistics* (November).

Vogel, Ezra. 1970. *Japan as Number One*. New York: Harper and Row.

_________. 1978. "Guided Free Enterprise in Japan." *Harvard Business Review* 56 (3).

Watson, Craig M. 1983. "Counter-Competition Abroad to Protect Home Markets." In *Managing Effectively in the Global Marketplace*, edited by Douglas Dickson. New York: John Wiley and Sons.

Weiss, Andrew. 1984. "Simple Truths of Japanese Manufacturing." *Harvard Business Review* (July–August).

Weston, J. Fred, and Dwang S. Chung. 1983. "Do Mergers Make Money?" *Mergers and Acquisitions* (Fall).

Whalley, John. 1984. "Trade, Industrial Policy, and Canadian Manufacturing, by Richard G. Harris (with the assistance of David Cox): A Review Article." *Canadian Journal of Economics* 17 (2) (May): 386–97.

Wheelwright, Steven C. 1981. "Japan: Where Operations Really Are Strategic." *Harvard Business Review* (July–August).

Williamson, Oliver E. 1975. *Markets and Hierarchies: Analysis and Antitrust Impications*. Cambridge, Mass.: Harvard University Press.

Woo, Carolyn Y. 1983. "Evaluation of Strategies and Performance of Low ROI Market Share Leaders." *Strategic Management Journal* 4.

Wood, Robert, Frank Hull, and Koya Azumi. 1983. "Evaluating Quality Circles: The American Application." *California Management Review* (Fall).

Woronoff, John. 1983. *Japan's Wasted Workers*. Totowa, N.J.: Allanheld, Osmun.

Wright, Richard, and Sadahiko Suzuki. 1984. "Financial Structure and Bankruptcy Risk in Japanese Companies." *Journal of International Business Studies*. (Winter).

Yip, George S. 1982. "Diversification Entry: Internal Development versus Acquisition." *Strategic Management Journal* 3.

The Canadian Aluminum and Steel Industries

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An appreciation of the Canadian aluminum and steel industries requires an understanding of their similarities as well as of their differences. Both are mature industries, largely Canadian controlled, well managed, and actively engaged in the adoption of new product and process technologies, both are cost competitive, and both were generally profitable throughout the 1970s. The two industries make a significant contribution to employment in certain regions of the country, and both view the U.S. market as important for their operating performance.

The aluminum industry of Canada is international in scope because it must rely entirely on imports to obtain raw materials and on exports to sell its output. The industry is located in Canada because of the plentiful supply of cheap hydroelectric power. In contrast, the steel industry is mainly oriented towards its domestic markets, and raw materials are plentiful in Canada. The energy needs of this industry are served primarily by coal.

The concentration of ownership in both industries is high. The domestic primary aluminum industry encompasses only two firms; one firm — Alcan — controls 85 percent of the market. However, since both firms have extensive foreign ties, a more relevant measurement of industrial concentration can be taken at the international level, where concentration has been decreasing in recent years. Similarly, the Canadian steel industry is an oligopoly in the domestic market, where three firms account for about 70 percent of crude steel production. It is only in recent years that the export market has grown in importance. Another recent development is the emergence of some small producers, or minimills, which have engaged in geographic mini-mills diversification, primarily in the United States.

Provincial governments have played a critical role in the operations of the aluminum industry in terms of the management of water rights and hydroelectric rates, as well as associated environmental policies. In the steel industry, regional employment considerations have led the governments of two provinces — Quebec and Nova Scotia — to acquire ownership of steel facilities, and two others — Alberta and Saskatchewan — to obtain equity positions in a steel firm, in order to establish a presence in steel production in their respective regions. In both industries, the federal government has taken a role in developing commercial policy and maintaining a fiscal environment conducive to capital spending in Canada.

The two industries are sufficiently different to require separate examination in this paper. The two following sections provide an overview of each industry, its development, and some possible problem areas. Some concluding remarks complete the paper.

The Canadian Aluminum Industry

The Canadian primary aluminum industry consists of only two producers, Alcan Aluminum Ltd. and Reynolds Aluminum Company of Canada Ltd. Alcan is Canadian owned and accounts for 85 percent of total Canadian smelter capacity, with plants in two provinces — Quebec and British Columbia. Alcan in turn owns extensive foreign operations and facilities involved in bauxite mining, alumina and aluminum production and fabricating. Reynolds, which is wholly owned by Reynolds Metals Company of the United States, accounts for 15 percent of Canadian smelter capacity and is located entirely in Quebec. The smelting capacity of these two enterprises in 1982 amounted to 1.2 million tonnes, or about 7 percent of the western (non-Communist) world's total capacity.

The industry depends heavily on international trade for both its inputs and its outputs. All the requirements for Canadian smelters are imported, either as bauxite or alumina, mainly from the Caribbean, West Africa, Australia and Japan. Up to 80 percent of the metal produced is exported. Most of the aluminum produced in British Columbia is exported to Japan, China and Southeast Asia, while the aluminum processed in Quebec is sold domestically and to markets in the United States.

Aluminum smelting is highly dependent on intensive energy use. The energy used in Canadian smelters is based entirely on hydroelectricity, which gives the Canadian industry a distinct competitive advantage over smelters in other countries, which must rely on high-priced oil or other fuels for electrical generation. The large quantities of hydro available in British Columbia and Quebec account for the location of the industry in these two provinces. This steady supply of hydro power has allowed the

Canadian industry to weather the recent world recession and the inflationary energy price rises of the 1970s that adversely affected aluminum production elsewhere. Because smelters in Japan and other countries are largely dependent on electricity produced from generators fueled by oil and natural gas, their smelter capacities have been severely reduced, either permanently or temporarily, as world oil prices have risen.

Canadian Industry Development and Performance

The Canadian aluminum smelting industry began as a subsidiary of the giant U.S. aluminum smelting enterprise, the Aluminum Company of America (Alcoa). Alcoa had built smelters at Arvida in 1926 (expanded from 1937 to 1943), Isle-Maligne and Shawinigan in 1941, Beauharnois in 1942, and Kitimat, where construction was begun in 1954. At the start of the century and up to 1950, Alcoa's Canadian plants accounted for over 25 percent of world aluminum production. The federal government encouraged the industry to expand during World War II, following a period in which international cartel agreements had existed in the industry. At the end of the war, the North American industry was restructured by a U.S. court order that separated the ownership of Alcan and Alcoa. Management separation had taken place in 1928. Meanwhile, two new firms, Kaiser and Reynolds, had entered the industry in the United States. At this time, over 80 percent of the primary aluminum smelting capacity in the western world was highly concentrated among six vertically integrated firms — Alcoa, Alcan, Reynolds, Kaiser Aluminum and Chemical Corporation, Pechiney-Ugine-Kuhlman and Alusuisse (Litvak and Maule, 1975). In North America, Alcan was second in size to Alcoa. It participated in the postwar growth of the international aluminum industry through both domestic and foreign investment.

In 1956, the sole owner of aluminum smelting facilities in Canada was Alcan, with 838,000 tonnes of capacity in Quebec and British Columbia. U.S. smelter capacity, by comparison, was 1,938,000 tonnes in 1956, some 2.3 times the Canadian capacity. The following year, Canadian British Aluminum Company began construction on a smelter at Baie-Comeau, Quebec, which was acquired by Reynolds in 1971. For a period of 25 years after 1957, no new smelters were built in Canada, for two main reasons. First, the postwar recovery encouraged investment outside North America, principally in Japan and Western Europe. Second, the long gestation period for new investment in the industry discouraged new capacity.

Between 1970 and 1982, Canadian primary aluminum production expanded by 10.3 percent and capacity expanded by 14.5 percent. Exports remained at about the same absolute level over this period, and ranged between 58.3 percent and 84.1 percent of production. Over the same period, there was no clear trend in imports, and imports as a

percentage of apparent Canadian consumption were less than 10 percent in all but four years. Apparent Canadian consumption showed an upward trend of 3.1 percent a year, from 251,000 tonnes in 1970 to 337,000 tonnes in 1981, though it declined sharply in 1982 (see Table 5-1).

Despite this growth, Canada's share of world primary aluminum production and capacity declined steadily.[1] In 1960, its share was 15 percent, down from 25 percent a decade earlier. Between 1970 and 1980, while world primary aluminum production increased by 59.2 percent and U.S. production increased by 29.0 percent, Canadian production rose only 9.8 percent. Capacity statistics reveal a similar picture. Although world primary aluminum capacity increased by 69.2 percent between 1970 and 1980, and U.S. capacity increased by 29.1 percent, Canadian capacity increased by only 3.3 percent.[2] Thus, at the start of the decade, Canadian production and capacity accounted for 10.1 percent of world production. By 1980, although both production and capacity had risen, Canada accounted for only 6.9 percent of world production (see Table 5-2).

Canada's relative loss of world production and capacity was due to the expansion of existing enterprises or the entry of new firms into the industry in other parts of the world. In 1970, there were 26 countries in the western world, including Yugoslavia, engaged in the production of primary aluminum, 11 of which had production in excess of 100,000 tonnes a year. By 1980, a total of 33 countries had undertaken aluminum production, of which 21 produced 100,000 tonnes or more. Large absolute and/or relative production increases were achieved in the United States, West Germany, Japan, Britain, Venezuela, Spain, Brazil, the Netherlands, Norway, Italy, Australia, and Yugoslavia.[3] As a result, the Canadian share of exports of aluminum as a percentage of exports by value from world market economies dropped from 21.2 percent in 1971 to 10.3 percent in 1981.[4]

While growth in the Canadian portion of the industry was slow, the Canadian-based Alcan was taking part in the global expansion. Alcan, which accounted for about 85 percent of Canadian capacity, expanded its international operations. During the decade 1971 to 1981, Alcan's primary aluminum production from its consolidated companies inside and outside Canada rose from 964,000 tonnes to 1,395,000 tonnes. Alcan's consolidated share of western world production was 10.5 percent in 1972, and 11.2 percent in 1981. During the same period, Alcan's consolidated mid-year capacity increased from 1,172,000 tonnes in 1972 to 1,454,000 tonnes in 1981. Alcan's capacity represented 10.9 percent of total western world capacity in 1972 and 10.3 percent in 1981.

On the other hand, Canadian production from Alcan declined from 9.9 percent of western world production in 1972 to 9.0 percent in 1981. Alcan's Canadian mid-year capacity rose from 1,089,000 tonnes in 1972

TABLE 5-1 Primary Aluminum Industry Production and Trade, Canada, 1970–82

	Production	Imports	Exports	Apparent[a] Consumption	Production Capacity	Exports as a Share of Production	Imports as a Share of of Apparent Consumption
	(thousands of tonnes)					(percent)	
1970	965	12	764	251	1069	79.2	4.8
1971	1020	16	810	293	1101	79.4	5.5
1972	921	35	702	304	1101	76.2	11.5
1973	945	46	703	333	1101	74.4	13.8
1974	1024	48	686	361	1101	67.0	13.3
1975	878	18	512	293	1069	58.3	6.1
1976	633	23	508	322	1052	80.3	7.1
1977	974	21	655	332	1052	67.2	6.3
1978	1048	11	863	380	1052	82.3	2.9
1979	860	24	552	399	1052	64.2	6.0
1980	1068	10	784	329	1120	73.4	3.0
1981	1116	14	725	337	1234	65.0	4.2
1982	1065	24	896	237	1234	84.1	10.1

Source: Canada, Department of Energy, Mines and Resources, *Canadian Minerals Yearbook* (Ottawa: Minister of Supply and Services Canada, annual).
a. Excludes metal used in producing secondary aluminum.

TABLE 5-2 U.S. and Canadian Shares of World Primary Aluminum Production, 1970–81

	U.S./World	Canada/World
	(percent)	
1970	37.3	10.1
1971	34.5	9.9
1972	34.0	8.3
1973	33.9	7.8
1974	33.8	7.8
1975	29.1	7.3
1976	30.6	5.0
1977	29.9	7.1
1978	30.9	7.4
1979	31.3	5.9
1980	30.3	6.9
1981	28.6	7.1
1982	24.7	8.0

Source: United States, Department of the Interior, Bureau of Mines, *Mineral Year Book* (Washington, D.C.: U.S. Government Printing Office, annual).

to 1,148,000 tonnes in 1981, but shrank as a share of western world capacity from 10.2 percent in 1972 to 8.1 percent in 1981.[5] Thus, Canada has participated in the expansion of the world primary aluminum industry through Alcan's foreign operations and through increased production in Canada. But while Alcan's total share of world production increased, the share undertaken in Canadian plants decreased. This has had an impact on Canada's balance of payments, reflected in the extent and nature of trade, dividend, and investment flows.

In comparison, between 1970 and 1982 Reynolds produced a total of 1,827,000 tonnes of metal in total in Canada, or an average of about 140,000 tonnes a year. During the decade, Reynolds' share of world production declined. Nevertheless, between 1983 and 1985, Reynolds hopes to increase its capacity by 115,000 tonnes a year at an estimated cost of $500 million, or $4,350 per tonne of capacity.[6]

Over 60 percent of Canada's smelting capacity is located in large plants which can produce more than 200,000 tonnes a year. All but 14 percent of this capacity was built in 1957 or earlier. After a 25-year hiatus in smelter construction after 1957, Alcan began construction on its Grande Baie smelter, which is expected to be fully operational in 1984. Announcements for further investment by Reynolds have also been made. In addition, some foreign-owned producers — Pechiney and possibly Alcoa — are committed to or are contemplating investment in Canada.

Canadian Adjustment to International Forces

The declining share of Canadian and U.S. industries in world production and capacity has been due to a number of factors. First, the postwar recovery of the European and Japanese economies included building smelter capacity in order to catch up with North America in the production of a metal which has military as well as other uses. Second, new sources of bauxite were discovered and developed, especially in Australia and Brazil. Though these markets were small, they also had access to economical energy for smelting. Third, the U.S. market for aluminum was large and expanding. Though energy cost levels varied with the energy source available, there was an incentive for existing firms to expand and for new firms to enter the industry in order to meet the demand. Many of these smelters were vertically integrated with fabricating plants located in the market where the products would be sold.

Although Canada possesses ageing smelter capacity, it has a competitive advantage in its economical hydroelectricity. A relative disadvantage lies in the fact that it lacks both raw material (bauxite) and a large market for finished aluminum products. Thus, the Canadian primary aluminum industry is strongly export oriented. Imports of processed aluminum account for only a small proportion of domestic consumption.

Alcan has adjusted to these developments in part by investing in various foreign countries. It has pursued a strategy of geographic as opposed to product diversification. The management has stayed with the base industry and thus has served Canada well in allowing the industry to adjust to the international shocks of the 1970s and 1980s. Early investments in fabrication were located in the United States, where its largest and most familiar market was found. Since then, it has invested in Europe, Asia, Latin America, and Africa,[7] with emphasis on forward integration into fabrication so as to provide an outlet for its smelters. In 1984, Alcan was mining bauxite in six countries, refining alumina in eight, smelting primary metal in nine, and fabricating metal in thirty countries.[8]

This international expansion took place mainly through individual firms and joint ventures between private investors, but it also often involved government investment. The estimated share of western world primary aluminum capacity with public sector participation between 1960 and 1980 rose from less than 10 percent to over 30 percent (OECD, 1983, p. 99). Alcan and Reynolds are among those participating in such joint ventures.

There are various reasons why governments participate with private firms in joint ventures. First, governments like to have a window on important industries, especially natural resource industries, in which the output is often viewed as part of the country's national assets to be

exported and commercialized in foreign markets. Second, governments feel that through ownership, their share of any resource rents can be both revealed and collected. And third, governments can take advantage of the distribution systems of foreign multinational companies in which various plants are vertically integrated to provide markets for raw materials, metals, or finished products.

Private firms use joint ventures to reduce the risk of having competitors gain access to a cheaper source of supply, to insure themselves against expropriation by foreign governments, and to establish a channel of communication with their competitors. Apart from prewar cartel agreements, there have been various cooperative arrangements used to stabilize the industry, especially the flow of metal to the West from Eastern Bloc countries such as the Soviet Union and Hungary. A 1973 OECD report gave implicit encouragement for cooperation on centralized investment decisions by the companies and pointed to the undesirable degree of competition from investments by new products (OECD, 1973, pp. 42, 71, 74). Other key advantages accruing to private firms from joint ventures are the spreading of commercial risk and the possibility of sharing knowledge on new technical developments.

One consequence of government participation in a joint venture is the different priorities that governments may have, such as maintaining output, employment, and exports in the face of declining demand, or willingness to accept lower prices and profits. This is suggested by the fact that only 10 percent of the western world's capacity that was shut down between 1980 and 1982 was government owned, although about 33 percent of total smelter investment was government owned.[9]

Newer entrants to the international aluminum industry include firms based in other resources, such as Noranda Mines Limited and Revere Copper and Brass Ltd., which have diversified from other metals into aluminum. Because some of these firms are often not vertically integrated with aluminum fabricating plants, there is more metal for sale outside the major producing enterprises. As a result of this situation, aluminum ingot prices have been quoted on the London Metal Exchange (LME) since 1978 and on the New York Comex, where spot sales have been made since 1984. The LME is supplied with metal from the Soviet bloc as well as from non-integrated producers. LME prices for ingot have become more influential, and the list prices of the major producers (from which discounts may occur) are no longer the only reference prices. In short, the price of ingot has become more volatile during the 1980s, as the OECD report of 1973 predicted. In April 1983, the LME price was US$0.617 a pound, whereas the Alcan export list price was US$0.794 a pound. For a period in 1982, the LME prices were as much as US$0.30 a pound below Alcan's list price.[10] All these developments took place

when energy prices were increasing substantially, except for electricity generated by existing hydro plants.

Besides the energy price shock, one other international development to consider is the formation and operation of the International Bauxite Association (IBA). The IBA was set up in 1974 and has eleven member countries. Haiti recently left the association and India is in the process of joining it. The Secretary-General of the IBA states that it is not a cartel. The name is, however, less important than what it does, which is to provide information and facilitate communication between member countries. It also recommends minimum prices and price ranges for bauxite and alumina as a proportion of the average American metal market list price for aluminum ingot.[11] The IBA members control about 75 percent of the world's bauxite, 37 percent of alumina, and 4 percent of ingot production, and about 90 percent of the non-Communist world's bauxite reserves (Litvak and Maule, 1982, p. 322). The association is one mechanism, along with joint ventures, by which governments can attempt to both monitor and influence their returns from the industry.

The impact of the IBA recommendations on bauxite costs, and thus on aluminum costs, is probably quite small. The cost of bauxite, including any levies charged by bauxite-producing countries, ranges from 5 to 10 percent of the total production cost. An estimate of the bauxite cost in U.S. smelters is 6 percent (Chase Econometrics, 1983, pp. 92–93). One conclusion is that: ". . . it seems somewhat unlikely that the incidence of bauxite-related taxation would affect new smelter decisions or, indeed, would significantly affect the competitiveness of existing smelters" (OECD, 1983, p. 46). The IBA has experienced the predictable problems of fragmentation common to cartel-like arrangements. Divergent views and interests are expressed by Australia, the Caribbean producers, Guinea, and Yugoslavia, while Brazil, a major source of bauxite, is not a member of the IBA.

In sum, the Canadian aluminum industry has had to adjust to international forces resulting from new entry (including government entry and joint ventures), declining international concentration, increased price flexibility, and the establishment of a producer-country association for bauxite. The adjustment has been made through the expansion of smelter and fabrication capacity which occurred partially in Canada but mainly abroad, where a combination of bauxite and energy costs and market expansion has attracted investment. New smelter capacity was built in Canada in 1982 and further capacity is projected for Quebec by Alcan and Reynolds, as well as by Pechiney in conjunction with the Quebec government. This new investment will permit Canada to have a large proportion of its capacity with lower energy and labour inputs, and thus become more competitive internationally. Canada has once again become attractive to new investment.

Technological Developments

Rising international energy costs affected the Canadian aluminum industry by making it relatively more competitive. The Canadian producers rely entirely on hydroelectricity as an energy source for smelting, where electricity charges make up 20 to 30 percent of the operating costs of a smelter (OECD, 1983, p. 42). The low hydroelectricity costs put Canadian producers at the lower end of the range for all producers, despite the greater age and greater energy use of the Canadian smelting facilities.

Japan is at the high end of the scale because it depends on coal and imported oil to generate electricity. Despite its newer, more energy-efficient facilities, Japan was adversely affected by the oil price increases of the 1970s. Since the energy price shock, about one million tonnes of primary aluminum capacity out of a total of 14 million tonnes produced in the western world has been closed down, additional capacity is at risk, and about 2 million tonnes of planned new capacity has been postponed or cancelled, a major portion in Japan.

The Canadian industry was able to survive because of its favourable energy assets. The hydro-generating facilities are company-owned. Because they were built years ago and the capital costs have since been written off, the ownership of hydroelectricity-generating facilities has provided the companies with "virtually inflation-proof energy."[12] However, the companies had little opportunity to sell off surplus power to other users because the smelters and their power plants are located in Quebec and British Columbia, which already have energy surpluses, and such sales would have brought the companies into competition with the provincial governments, which had sold or leased them the water rights to generate the hydroelectricity in the first place.

The variation in electricity consumption and labour productivity per tonne in Canadian smelters is due to the age variation of the smelters and the technology embodied in them. Electricity efficiency for smelting varies from 18,000 kilowatt-hours per tonne at Arvida and Baie-Comeau to 14,500 kilowatt-hours per tonne at Grande Baie. The best possible rate with the latest technology is between 13,000 and 14,000 kilowatt-hours per tonne, and Alcan's Laterrière smelter is estimated to use 13,200 kilowatt-hours per tonne. Labour productivity also varies greatly, with output per employee at Grande Baie amounting to 263 tonnes, compared with only 160 tonnes per employee at the older Arvida plant.[13]

During the 25-year hiatus in smelter construction in Canada, improvements were being made to the energy efficiency of existing smelters as technology evolved. New smelters, using the latest technology, require about 25 percent less energy per tonne of metal produced than smelters built during the 1950s. However, there have been no radical changes in smelter technology, so the Canadian industry with its older facilities could continue to compete internationally.

Although modernization has taken place at the older smelters, it appears to require the construction of new facilities to utilize newer, more energy- and labour-efficient technologies (OECD, 1983, p. 26). This has happened at Alcan's Grande Baie smelter which opened in 1982, and will occur in new facilities to be built in Quebec.

Companies have engaged in research and development related to the various stages of production. For raw materials, this has involved extracting aluminum from non-bauxitic ores. In smelting, the search was for ways to reduce energy inputs and to carry out the direct reduction of aluminum from bauxite. Fabrication processes developed continuous casting to make different products. End-use experimentation sought the development of new end uses such as automobile parts normally made from heavier metals, containers to replace glass and plastic bottles, and fuel cells (Butcher, 1982, ch. 9; U.S. Bureau of Mines, 1983, p. 5).

The Canadian industry has participated in joint research projects to extract aluminum from different ores, has modernized its older plants using available technology, and has undertaken some development work. However, the United States, France and Japan are generally considered to be doing the most advanced work in developing new smelter technology. This is probably because the pressure of energy costs forces these countries to look for energy savings. Canadian producers have been able to incorporate these developments in their new smelters and, where possible, in the old ones as well.

Technological developments in continuous casting have taken place in Europe, as with Alusuisse's Caster Two process. Alcan has built a combined sheet and foil mill using continuous roll-casting technology, which it developed. A major area for R&D has been finding new end uses. A current example is Alcan's work on the aluminum air battery or fuel cell, which extracts the energy from aluminum plates in a chemical reaction. The system uses plates as anodes, caustic soda and tap water as the electrolyte, and air as the cathode. The aluminum plates dissolve, releasing electric energy, and are replaced when they are used up (Alcan, 1982, p. 9).

The aluminum industry presents a wide range of opportunities for technological development. Each company chooses where it will spend its limited resources for R&D. Alcan appears to have emphasized fabrication and end uses, and to have utilized the results of developments undertaken by other companies. The presence of joint ventures may have permitted the companies to monitor each others' activities, and to utilize results produced by other firms.

Alcan organizes its R&D in four laboratories in Arvida, Quebec; Kingston, Ontario; Banbury, United Kingdom; and in Japan. The technology and engineering staffs number about 1,200. In addition, each major operating subsidiary has a facility concerned mainly with quality control and process improvements. The overall organization of R&D is

international in scope, and new developments are monitored globally. A new experimental engineering centre for smelting technology was opened at Arvida in 1981, suggesting an increased emphasis on smelters at a time when the company is building and planning new capacity in Canada. For example, Alcan's new smelter at Laterrière, Quebec, with a capacity of 248,000 tonnes, is due to open in 1988–90, and will use less electricity than the Grande Baie smelter (opened in the 1980s) and 25 percent less electricity than the old Arvida smelter. In 1982, the company reported R&D expenditures of $55 million, about 1 percent of sales revenue, making it the seventh largest spender on R&D in Canada. Sixty percent of the expenditures is now aimed at the raw material and smelting processes.[14]

The Impact of Policies

Conditions are now ripe for expansion of the industry in Canada. The policies which will be crucial in this regard are provincial policies on water rights and electricity rates. Canada may forego some of the economic benefits from the industry if the provinces compete against each other in providing unduly low energy costs to producers. Environmental policies will also condition the amount of new investment. At the federal level, commercial policy is important in gaining access to foreign markets. Foreign tariffs on fabricated products provide an incentive for Canadian firms to locate behind the tariff wall as opposed to investing in fabricating facilities in Canada, such as occurred with Alcan's recent acquisition of the Atlantic Richfield Company's aluminum assets in the United States.

Provincial government policies have a major impact on the location of smelters and the cost of their operations. The sale or lease of water rights negotiated by the companies with the provincial governments of British Columbia and Quebec are the principal influences which the provinces can exert. Once the companies have decided where to locate, they are in some sense captives of the provinces although, for employment and tax revenue reasons, the governments need the companies as much as the companies need them.

While long-term contracts can be negotiated and can create certainty for the companies, economic and political factors can bring pressure for change. In many areas, multinational firms anticipate that concession agreements with governments will be either broken or modified, regardless of what was signed originally. Despite the existence of the rule of law in Canada, such a situation has in effect occurred with the discussions held by the government of British Columbia with Alcan over water rights in the Kitimat-Kemano region (Alcan, 1983). The government that negotiated the agreement in 1950 was not subject to the

pressures from environmental groups now in existence which are forcing consideration of additional issues. In Eastern Canada, Newfoundland is attempting to renegotiate its power agreement with Quebec, partially in the hope that facilities such as aluminum smelters might be built in the province if cheap power were available. Atlantic Richfield undertook a feasibility study for a smelter in Newfoundland, but for political reasons the prospects for cheap power were not good.[15] Subsequently, Atlantic Richfield withdrew from the aluminum industry by selling most of its U.S. assets to Alcan.

In the Canadian aluminum industry, companies can play one provincial government off against another, and the governments can act likewise with the companies. Unless there is relatively equal bargaining strength, governments may grant concessions to companies through either the sale of energy produced by provincially owned facilities or the sale or lease of water rights. The loss of resource rents may result in larger payments to the provinces from the federal government through the equalization process.

Subsidies provided by foreign governments to Canadian or foreign firms to build plants abroad may have the effect of diverting investment in smelter and fabrication facilities away from Canada. Such action may arise from the payment of direct or indirect subsidies or from government participation in aluminum operations. In the past, one reason Alcan constructed fabricating facilities in the United States was that the U.S. tariff on aluminum ingots was lower than its tariff on fabricated aluminum products.

The current benefits to Canada from having a major aluminum producer would have to be measured in terms of the net direct and indirect economic effects from employment, taxation, and external trade in goods and services, as well as the effect of capital inflows and outflows. The Canadian parent company may be the recipient of interest, dividends, management fees, and royalties from its foreign subsidiaries.

In summary, the industry appears to have adjusted well to the various developments of the past decade, including increasing international competitiveness. After a period in which there was little increase in new smelter capacity, the combined changes in energy costs, raw material costs, and markets is again making Canada an attractive place for new smelter investment, at a time when capacity is being reduced and plans shelved in other countries. Whereas Canada for a period had some of the world's older smelters, the new investment will incorporate technology which will modernize the industry. The delay in bringing this about is due to the longevity of the fixed assets and the fact that there have been no radical changes in smelter technology. New investment in Canada and elsewhere is being assisted by industrial policies that benefit the producers. As a result, governments may be induced to bid against each

other for that investment. A recent OECD study concludes that the main policy issues for the international aluminum industry are "the lack of transparency of power prices and pricing mechanisms governing power supply contracts" and possible distortion of energy market signals by power pricing policies applied to smelters (OECD, 1983, p. 88).

The Canadian Steel Industry

The Canadian steel industry is regarded as one of the more efficient in the world. In 1982, Canada produced some 13.9 million tonnes, accounting for about 2 percent of the world's production of raw steel (Schottman, 1983, p. 2), and ranked as the world's fourteenth largest steel-producing country.[16] Three large integrated producers — Algoma Steel Corporation, Dominion Foundries and Steel Corp. (Dofasco), and Steel Company of Canada Limited (Stelco) — accounted for approximately 71 percent of Canada's raw steel capacity, and ranked as the twenty-fifth, thirty-third, and forty-sixth largest steel producers, respectively, in the world.[17]

The industry is Canadian-controlled, and government ownership and direction is not significant compared with the role played by governments in other steel-producing countries. High rates of capacity utilization, increased employment and high levels of productivity and profitability have characterized the performance of the Canadian steel industry. During the 1970s, despite the limitations of a small domestic market and the implications of size for economies of scale, the Canadian steel industry managed to become the most profitable one in the world (Barnett and Schorsch, 1983, p. 224). Several strategic elements led to this success:

- a high degree of product specialization to achieve economies of scale and international cost competitiveness;
- minimization of interfirm rivalries by virtue of specialization;
- maintenance of high operating rates by bringing on sufficient productive capacity only for markets in which a comparative advantage could be realized, taking into account transport costs and tariffs;
- the servicing of excess demand and/or unprofitable markets via imports (though in times of economic downturn some of the unprofitable geographic and product markets were serviced by the domestic steel producers); and
- the early adoption of new technologies for products and processes, largely from foreign sources.

Although the Canadian steel industry traditionally has been oriented toward its domestic markets, during the early 1980s it has had to increase its exporting efforts in order to counter declining domestic sales. Several

recent trends have combined to affect adversely the operating performance of the Canadian steel industry. These include:

- new domestic capacity brought on stream during the mid to late 1970s;
- the negative impact of the National Energy Program and the shelving of mega-projects;
- the greater material substitution of steel with aluminum and plastic; and
- the efforts of offshore steel producers to increase their Canadian market participation.

The Canadian steel industry will face a more turbulent market environment during the late 1980s. Domestically, greater interfirm rivalries have already emerged and have altered some of the more stable competitive market relationships which characterized the Canadian steel industry during the 1970s. Simultaneously, steel producers in the United States, Europe and Japan are engaged in strategies of rationalization and modernization. Meanwhile, certain newly industrialized countries such as South Korea have become important steel-producing powers in the international market place and threaten to challenge the Canadian industry in the domestic market and in various export markets such as the United States.

The Corporate Landscape

The Canadian primary iron and steel industry is made up of firms that produce steel and roll it into primary mill shapes.[18] Preliminary data from Statistics Canada indicate that in 1980, there were 39 enterprises with 55 establishments in the iron and steel mills industry (industry SIC 2910 in the Standard Industrial Classification system). Shipments were valued at about $6.5 billion. The leading four enterprises accounted for 77.9 percent of this amount, and the leading eight for 90.3 percent of the total.[19] Table 5-3 lists Canada's crude steel production, trade, and consumption figures for the years 1970–82.

The industry is made up of two major groups of producers. The first and most important group consists of the five integrated producers. Four of the five — Algoma, Dofasco, Stelco, and the Sydney Steel Corporation (Sysco) — employ the coke-oven/blast-furnace method, while the fifth firm — Sidbec-Dosco Limitée — employs the sponge-iron/ferrous-scrap/electric-furnace process.

This first group can be further subdivided. The first category, in rank order, includes Stelco, Dofasco, and Algoma. These three privately owned firms are commonly referred to as the "Big Three." One key distinguishing feature of the three major steel producers is their degree of vertical integration, especially "upstream" into iron ore, coking coal, and limestone. In 1982, the Big Three accounted for approximately 71

TABLE 5-3 Crude Steel Production, Trade and Consumption, Canada, 1970–82

	Production	Imports	Exports	Indicated Consumption	Production Capacity	Imports as a Share of Consumption	Exports as a Share of Production
	(millions of tonnes)					(percent)	
1970	12.3	2.2	2.3	12.2	14.1	18.0	18.7
1971	12.2	3.1	2.1	13.2	15.5	23.5	17.2
1972	13.1	2.8	1.8	14.0	15.5	20.0	13.7
1973	14.8	2.6	1.8	15.6	16.0	16.7	12.2
1974	13.6	3.6	1.7	15.6	16.7	23.1	12.5
1975	13.0	1.7	1.2	13.6	17.0	12.5	9.2
1976	13.3	1.4	1.9	12.8	17.3	10.9	14.3
1977	13.6	1.5	2.2	12.9	17.5	11.6	16.2
1978	14.9	1.6	2.9	13.6	18.0	11.8	19.5
1979	16.1	2.3	2.8	15.6	18.6	14.7	17.4
1980	15.9	1.4	3.8	13.5	18.9	10.4	23.9
1981	14.8	3.4	3.6	14.6	20.4	23.3	24.3
1982	11.9	1.3	3.6	9.5	21.8	13.7	30.3

Source: Canada, Department of Energy, Mines and Resources, *Canadian Mineral Yearbook* (Ottawa: Minister of Supply and Services Canada, annual).
Note: Data may not add to totals because of rounding.

percent of Canada's raw steel capacity. In terms of 1982 sales, the performance of the three companies was as follows: Stelco, $2 billion; Dofasco, $1.5 billion; and Algoma, $880 million. Stelco produced approximately 35 percent of Canada's steel in 1982.

The headquarters organization of these three companies, the bulk of their capital investment, and the major concentration of their customers are in Ontario. Stelco's head office is in Toronto, with steelmaking facilities located in Ontario, Quebec, and Alberta. Dofasco's head office and principal steelmaking facilities are located in Hamilton. Algoma repeats this pattern of geographic concentration with its location in Sault Ste. Marie, Ontario.

Dofasco manufactures primarily flat rolled and coated products; Algoma emphasizes structurals, rails, and plates; and Stelco is the only one to have a broad product mix. By 1981, the average capacity of the large plants operated by the integrated producers was comparable in Canada and the United States (see Table 5-4).

TABLE 5-4 Comparison of U.S. and Canadian Steel Industry Performance, 1958 and 1981

	1958		1981	
	Canada	U.S.	Canada	U.S.
Imports as a share of apparent consumption (percent)	24.7	3.3	15.9	17.6
Exports as a share of total shipments (percent)	9.8	4.7	24.4	3.5
Average integrated plant capacity (millions of net tons)	1.3	2.5	4.0	3.8
Productivity (Person-hours per net ton of cold-rolled sheet	12.5	11.5	6.3	7.0
Hourly employment costs (US$)	2.75	3.75	12.75	20.1
Iron ore costs, c.i.f. (US$ per ton)	10.50	10.64	38.50	40.0
Coal costs, c.i.f. (US$ per ton)	11.00	10.50	61.00	57.5
Coke rates (ratio of coke to iron)	0.75	0.80	0.43	0.5
Estimated production cost per ton of cold-rolled sheet (US$)	120.00	122.00	355.00	445.0
Price per ton of cold-rolled sheet (US$)	130.00	130.00	385.00	460.00

Source: D.F. Barnett and L. Schorsch, *Steel* (Cambridge, Mass.: Ballinger, 1983), p. 218.

To meet both domestic and foreign competition, the key private sector firms formulated and implemented strategies that emphasized overall cost leadership combined with new approaches toward customers, products, and market segmentation.[20] In this context, one of the key decisions taken by management has been capacity expansion.

> It is probably the central aspect of strategy in commodity-type businesses. Because capacity additions can involve lead times measured in years and capacity is often long-lasting, capacity decisions require that firm to commit resources based on expectations about conditions far into the future. (Porter, 1980 p. 324)

Unlike the privately owned "Big Three," the other two integrated producers — Sidbec-Dosco and Sysco — are controlled by the provincial governments of Quebec and Nova Scotia, respectively. Furthermore, while the operations of the Big Three have been consistently profitable,[21] the two government enterprises have been consistent in losing money. To a significant degree, the poor financial performance of Sidbec-Dosco and Sysco can be attributed to a heavy debt structure, lack of modern and up-to-date manufacturing facilities, and poor management. Their steelmaking facilities are located in Quebec and Nova Scotia.

The second major group of firms are the non-integrated companies, often referred to as mini-mills. These companies produce steel in electric furnaces. The major firms in this group are: Atlas Steels, Burlington Steel, Interprovincial Steel and Pipe Corporation Limited (Ipsco), Ivaco Inc., Lake Ontario Steel Company Limited (Lasco), Manitoba Rolling Mills, and Western Canada Steel Limited. With the exception of Atlas Steels, which specializes in stainless, tool, and alloy steel, all of the companies produce carbon steels.

The steelmaking capacity of Ipsco, Manitoba Rolling Mills, and Western Canada Steel are located in the Prairies and British Columbia; Burlington, Ivaco, and Lasco in Ontario; and Atlas in Ontario and Quebec. The mini-mills have low capital requirements and tend to fill a niche in the marketplace by producing a narrow product line for regional markets. Some of the mini-mills, however, have expanded into the United States, notably Ivaco and Co-STEEL Inc., the parent of Lasco.

Over four-fifths of Canada's steelmaking capacity in 1982 was held by the private sector. As previously noted, Sidbec-Dosco and Sysco are provincially controlled. In addition, the governments of Saskatchewan and Alberta each hold a 20.2 percent interest in Ipsco, the sixth largest steel producer in Canada. The breakdown of Canada's steel production capacity by province in 1982 was as follows: Ontario, 79 percent; Quebec, 9 percent; Nova Scotia, 4 percent; Saskatchewan, 3 percent; Alberta, 2 percent; Manitoba, 2 percent; and British Columbia, 1 percent. It is estimated that the industry is about 95 percent Canadian owned.

Just as ownership in the Canadian steel industry is largely Canadian, so is the management. Many of the senior executives have educational and career backgrounds in engineering and production in Canada, such as the chairman and chief executive officer, and the president and chief operating officer of Stelco in 1983. Both are graduate engineers. A strong emphasis on production combined with a commitment to pursuing investment and market opportunities in steel have characterized many of the key strategic decisions made by Canadian steel firms during the 1970s. Diversification outside the steel industry has been minimal.[22]

Coal, iron ore, and scrap iron and steel are the three major raw material inputs in the production of steel. The choice of domestic or imported material depends on quality and cost, as delivered to the mill. Transportation costs are a large part of raw material cost and vary depending on the method of transport and distance.

The cost of using Alberta coal in Canadian mills in 1981 was $24 a tonne higher than for coal from West Virginia, because of the difference in transportation cost. The much shorter rail haul and cheaper ocean-shipping costs reduced the net cost of Alberta coal to Japanese mills below the cost for the same coal to Ontario mills. Based on 1981 coal purchases of 6.2 million tonnes, if Canadian producers had used Canadian coal, their costs would have been $150 million greater.

Most of the iron ore used by the Canadian industry comes from domestic sources in Northern Ontario and the Quebec/Labrador trough. Significant quantities also come from Minnesota and Michigan. One of the major factors that determine which source to use is the availability of incremental quantities at an acceptable price. New mines are normally viable only if they can sell at quantities far in excess of the incremental amounts of tonnage required by most individual companies. Shopping for incremental tonnage volumes has led some companies to buy from iron ore sources located in the United States, despite the large net flow of iron ore in the other direction. Interestingly, because of the higher costs of operating lake boats rather than ocean-going vessels and because of the tolls paid for using the St. Lawrence Seaway, iron ore from the Quebec/Labrador area can be delivered to European steel mills at prices comparable with delivery of the same iron ore to Canadian mills.

Canada has traditionally been a net importer of scrap, and the United States accounts for almost all imports into Canada. The United States, in turn, is by far the largest buyer of Canadian scrap exports.[23]

Employment in the Canadian steel industry grew from approximately 35,000 workers in 1960 to 61,000 workers by 1980. Employment growth over this 20-year period averaged 2.8 percent a year, with an overall growth of more than 70 percent. In comparison, the total increase in manufacturing employment from 1961 (earliest data available) to 1980 was only 30 percent.[24]

Although growth in employment in the Canadian steel industry slowed down during the 1970s, the record remained favourable compared with the performance in other industrialized countries, where steel industry employment has declined more significantly (see Table 5-5).

TABLE 5-5 Change in Employment in the Steel Industry, Six Countries, 1974–81

	Percentage Change
Canada	+2
United States	−24
France	−39
West Germany	−19
Japan	−20
United Kingdom	−55

Source: International Iron and Steel Institute, *World Steel in Figures*, (Brussels: 1983), p. 18.

However, in 1982, the industry employed only 54,000 workers, four-fifths of whom were located in Ontario. About 12,000 more workers were involved in some form of layoff. With the exception of Dofasco, which is non-unionized, most of the workers are members of the United Steelworkers of America. The approximate regional employment breakdown is shown in Table 5-6.

TABLE 5-6 Employment in the Steel Industry, Canada, 1982

	Total	Percentage
Nova Scotia	2,500	4.6
Quebec	4,800	8.9
Ontario	44,000	81.4
Manitoba	600	1.1
Saskatchewan	800	1.5
Alberta	800	1.5
British Columbia	500	1.0
Total	54,000	100.0

Source: Information supplied by the Department of Regional and Industrial Expansion.

Four points should be noted when observing employment performance. First, because of the introduction of new technology, heavy manual-labour jobs are being eliminated and/or substituted by upgrading the job content with requirements calling for higher skills. Second, new opportunities for professional manpower for such personnel as engineers, accountants, and computer specialists were generated during the 1970s as technological developments and expansion programs were being undertaken by Canada's steel producers. Third, the steel industry has continued to pay higher than average wages. As of July 1983, average weekly earnings in the iron and steel industry were 33 percent higher than the average for all manufacturing and 48 percent higher than the

industrial aggregate.[25] Since 1980, although employment declined, average weekly earnings have been pushed further ahead of the industrial composite as a result of 1981 wage settlements. Fourth, Canadian productivity is very high; in the 1970s it ranked second only to Japan in productivity measured by output per employee.

Technological Developments

The steel industry's commitment to research and development (R&D) is not a strong one. In a recent survey of leading R&D spenders in Canada, Stelco was the only steel producer to appear on this list. With a budget of $9 million, it ranked thirty-first in 1983 (Blackwell, 1983, p. 28). Stelco's ratio of R&D to sales was less than one-half of one percent (0.44 percent). Between 1977 and 1983, its annual ratio of R&D to sales never exceeded 0.5 percent. The overall expenditure level of R&D in the Canadian steel industry, as a percentage of sales, is lower than Stelco's. In 1981, direct employment of staff in R&D for steelmaking by the industry totalled 302 person-years (Canadian Steel Industry Research Association, 1983, p. 13). Stelco, which produced approximately 35 percent of the nation's steel, accounted for 40 percent of the industry's person-years devoted to R&D.

There are, in addition, many other engineers and scientists both within and outside the industry whose work is directed to supporting research and development programs. The outside networks include provincial research institutes and universities in British Columbia, Alberta, Saskatchewan, Ontario, and Quebec.

Compared with the Canadian steel industry's low contribution to R&D, the ratio of net sales revenue to R&D in the U.S. steel industry during the 1975–80 period was only marginally better at less than 0.6 percent. In sharp contrast, Japanese steel firms "allegedly devote 1.6 percent of net sales revenues to R&D" (Barnett and Schorsch, 1983, p. 60). In steel, Japan sells more technology than it buys. Of the major Canadian steel producers, Stelco is the only one to have some balance in its trade account involving technology transactions. The Canadian steel industry is a substantial buyer of foreign technology.

The steel industry is characterized by significant technical interchange among firms. Canadian management has actively pursued the adoption and/or improvement of technologies developed by other companies anywhere in the world. Dofasco, for example, is committed to developing its own programs for technological improvements, in addition to exchanging technical information with other steel producers. In 1983–84, it completed a detailed study of its operating and technical practices in comparison with those of a major Japanese steel producer, in order to learn from the Japanese experience and thereby to improve its own quality, productivity, efficiency, and profitability performance. In

undertaking this study, the Canadian steel industry contradicted the findings of previous research, which suggested that Canadian management "are much slower in incorporating what is currently 'best practice,' compared to their counterparts in other countries such as the United States" (Daly, 1984, p. 21).

While numerous technological developments have taken place in the steel industry, two have made major contributions to the steelmaking process. First was the oxygen converter, which revolutionized the steelmaking process. In 1954, Dofasco was the first steel mill in North America to introduce the basic oxygen process of making molten steel, at a time when the process had been proven only in Austria and Germany. Second was continuous casting, which eliminated four steps from the conventional steelmaking process and conserved substantial quantities of energy. Atlas pioneered the use of continuous casting in North America.

The efficiency of the Canadian steel industry can be attributed to its commitment to achieving cost effectiveness, which includes acquiring the most up-to-date technologies at the earliest point of introduction. The importance of adopting advances in steelmaking should not be underestimated. Contrary to popular perception, the American steel industry outspent the Japanese by about 20 percent for each ton of production capacity added or replaced between 1950 and 1979. Nonetheless, the Japanese industry is more modern and better able to compete domestically and internationally than the American industry. The underlying cause for this difference is attributable to poor management decisions in the United States and to the fact that the major integrated steel-producing firms were late in adopting two of the critical breakthroughs in steelmaking — the basic oxygen furnace and continuous casting.[26]

Markets and Trade

There is considerable product specialization in the steel industry. For example, Stelco and Algoma account for much of the plate production in Canada, while Atlas Steels specializes in the production of stainless steel, and Ipsco concentrates on pipes and tubes. The decision of the larger steel producers to specialize in certain products has permitted entrants such as Ipsco, Lasco, and Ivaco to find a corner of the market which they can serve.

> New entrants often seek special product line segments, especially those inadequately served by existing sellers, in which they can sustain price premia compensating for the cost penalties of small-scale operation. A frequent concomitant of such niche-filling strategies is building a plant which can be expanded readily once a market beachhead has been secured. (Scherer et al., 1975, p. 154)

In a submission to the Royal Commission on Corporate Concentration, Stelco (1975) argued that the smallest efficient size for a primary steel mill based on the blast-furnace/oxygen-furnace technique is two million tons a year, and that the preferable size is four to five million tons a year. Nonetheless, the entry and continuing existence of smaller firms such as Ipsco, Lasco, and Ivaco means that the cost disadvantages of smaller scale can be overcome. In no small measure, the cost disadvantages have been overcome as a result of the niche-filling strategy, the regional character of the Canadian market, and the type of steelmaking technology employed, such as electric-furnace technology. In addition, it is not known exactly what cost disadvantages are incurred by operating at less than optimal size or what economies of scale are associated with different products.

Steel consumption is heavily influenced by demand in the capital goods sector. Cyclical changes in demand from this sector, together with large inventory swings, have meant that the domestic demand for steel is much more volatile than overall economic activity. In 1982, a decline of 4.4 percent in real gross national product (GNP) was associated with a 35-percent drop in steel shipments taken by the Canadian market.

In addition, steel usage as measured by the ratio between the consumption of steel and GNP, referred to as the "steel intensity" or "demand intensity," has been declining for a number of years. This decline has been accelerated by the rise in energy prices, which has prompted industry and consumers to adopt greater conservation measures in the use of steel. For example, the quantity of steel consumed by the U.S. automobile industry, the leading market for the Canadian steel industry, has declined by over 40 percent as higher energy prices have encouraged weight reduction in automobiles.[27] A similar change is taking place in the can industry, where aluminum is replacing steel cans.

The production and marketing efforts of the Canadian steel industry have been primarily concentrated in the domestic market. In the 1970s, Canadian exports of steel averaged about 15 percent of domestic production, most of which was exported to customers located in the Great Lakes region of the United States. Imports were more cyclical on a yearly basis, and ranged from 10.9 percent to 23.5 percent of Canadian production (see Table 5-3).

An important element in the corporate strategies employed by the Big Three steel producers has been to expand their productive capacities to meet the current and projected requirements of their Canadian customers. A major result of this orientation has been the achievement of consistently high levels of capacity utilization, coupled with world price competitiveness.

Canada's capacity utilization rate during the 1970s was superior to that of other major steel-producing countries. Furthermore, a healthy Cana-

dian economy and the promise of more and bigger mega-projects encouraged the Canadian steel industry to undertake an aggressive program. Investment for modernization and expansion by Stelco, Dofasco, and Algoma averaged $300 million per year during the 1970s.

It has been estimated that from 1961 to 1979, annual capital investment in steel in both Canada and Japan could have replaced 4 percent of facilities each year, compared with 2.9 percent per year in the United States. Consequently, the average age of steel facilities is 11 to 12 years in Canada and Japan, compared with 17.5 years in the United States.[28]

During the 1970s, there was room for imports because of product specialization by the steel firms, and because of conservative expansion in Canadian steel capacity, which allowed imports to fill any excess demand that developed (Litvak and Maule, 1977, p. 71).

From 1970 to 1979, capacity utilization averaged about 90 percent. In recent years, Canadian steel firms have introduced new products previously imported, and they have undertaken exporting as a commercial necessity because of additional capacity coupled with a declining domestic demand.

Although the manufacturing and marketing efforts of the Canadian steel industry have been oriented towards the domestic market, the export trade in steel since the mid-1970s has grown substantially, particularly with the United States. For most of those years, Canada has been a net exporter of steel. Furthermore, because of the current economic slowdown in Canada, success in exporting is regarded as critical by the Big Three, as well as by some of the other steel firms, such as Atlas. Consequently, protectionism in foreign markets, especially in the United States, is viewed with great concern.

The current concern with protectionist measures and policies in the United States looms large in the strategic thinking of the Canadian steel industry. Not only is the United States Canada's most important steel export market, but also it has become a critically important one in terms of its operating performance. To underline the significance of the U.S. market, a coalition of Canadian steel producers, the Canadian government, and unions has been formed to actively lobby the U.S. government and other interest groups against the possible imposition of quotas on Canadian steel imports to the United States.

The Impact of Policies

The growth and performance of the Canadian steel industry following the Second World War has been a remarkable one. A benchmark study by Barnett and Schorsch (1983) notes that the Canadian steel industry was inefficient by world standards during the early 1950s but had grown into one of the world's most efficient and profitable steel industries by 1980. This transformation can be gleaned from Tables 5-4 and 5-7, which

compare the Canadian and U.S. performances for the years 1958 and 1981.

A major catalyst in this transformation was the "policy-strategy consensus" established between industry and government. In brief, acknowledging the limitations of a small domestic market, the large integrated firms adopted a strategy of product and market specialization as a necessary precondition for achieving economies of scale. It is alleged that the Canadian government applied its anti-combines legislation "in such a way as to allow the allocation of markets among different firms" (Barnett and Schorsch, 1983, p. 219).

As previously noted, the Canadian steel industry's performance has been

> . . . achieved by gearing production capacity to average rather than peak Canadian forecast demand, and by constructing modern, efficient, state-of-the-art technology plants at times when international competitors were utilizing less efficient, obsolete facilities. This has enabled the industry to enjoy high capacity utilization rates, with imports satisfying peak requirements and exports, primarily to the United States, increasing during cyclical troughs. (Canada, Department of External Affairs, 1983, pp. 79–80)

Despite this performance, the Canadian steel industry faces challenges that could limit its competitiveness and efficiency. The most significant is from the United States, where steel firms facing international competition have taken steps to limit imports through protectionist measures. Rather than responding with product and process innovation, the U.S. industry has invoked legal measures such as dumping complaints and litigation, and has lobbied for various types of trade restrictions in order to meet the competition. Reich (1983) refers to this response as "paper entrepreneurialism."

Federal commercial policy appears to be the most important area of interest and concern to the Canadian steel industry as a necessary step to overcome the setbacks forecast for it during the 1980s. First, the industry wants to ensure that Canadian steel producers are not disadvantaged by unfair competition from offshore suppliers. Second, they wish to ensure that Canadian steel producers have fair access to foreign markets, particularly in the United States. Third, the industry wants to ensure that special bilateral arrangements with the United States, such as the Canada–United States Automotive Products Agreement (the Autopact) provide the maximum benefits for Canadian producers of steel, given that the automotive industry is the largest manufacturing consumer of steel. The steel industry has voiced concern about trends in imports of cars and auto parts and about the imbalance between vehicle assemblies and parts production in Canada.[29]

Some Canadians have suggested that serious consideration be given to exploring the possibility of establishing a limited Canada–U.S. free trade arrangement in steel, and the specialty steels could be the first

TABLE 5-7 Comparison of Canadian and U.S. Steel Industry Performance, 1958–81

	1958 – 64		1964 – 72		1972 – 81		1958 – 81	
	Canada	U.S.	Canada	U.S.	Canada	U.S.	Canada	U.S.
Growth in apparent consumption (percent)[a]	5.7	3.4	6.2	2.8	0.9	1.2	3.9	1.4
Growth in total shipments (percent)[a]	8.4	2.2	5.6	2.1	2.7	1.7	5.1	0.6
Capital expenditure per tonne shipped (US$)	26.00	16.88	24.00	21.55	41.50	33.50	31.15	24.67
Productivity improvement (percent)[b]	5.5	3.1	3.1	3.2	1.9	0.8	3.3	2.3
Return on equity (percent)	12.1	7.5	10.4	7.1	12.8	8.7	11.9	7.7

Source: D.F. Barnett and L. Schorsch, *Steel* (Cambridge, Mass.: Ballinger, 1983), p. 223.

a. Calculated using five-year averages around year listed.

b. Raw steel production divided by total person-hours worked (all products); exaggerates improvements for any one product because of changes in product mix (bias greater for United States than for Canada).

product introduced in this process. Other reasons offered for promoting a free-trade option include: the commitment by the GATT to reducing tariff rates on steel products; the current foreign exchange differential which works in favour of Canada; and Canada's cost advantage in competitive transportation systems that give Canadian producers access to potential customers in the Great Lakes region of the United States. Nevertheless, the pursuit of this option entails some obstacles, such as the concern about the potential introduction of non-tariff barriers in the United States. Unlike the situation in the auto industry under the Autopact, the Canadian steel industry is Canada-controlled and is competitively superior to the U.S. steel industry.

Access to raw materials is also a potentially important consideration in relations between the steel industries in Canada and the United States. For example, in a ten-year period, the capacity of Canadian electric furnaces rose from 1.87 million tonnes and 13.4 percent of total Canadian crude steelmaking in 1970 to 4.45 million tonnes and 23.3 percent of capacity in 1980. In the United States, the share of total crude steelmaking capacity accounted for by electric furnaces during the same period rose from 12.8 to 23.5 percent (McMullen and Pope, 1982, p. 18). As a consequence of this expansion, there has been a large increase in the demand for scrap, a product which has been subject to control by many governments, including that of the United States.

> In the event of any action by the United States to control export of scrap, consideration would have to be given to seeking a bilateral agreement to maintain traditional flows. (McMullen and Pope, 1982, pp. 48–49)

Concluding Remarks

Over the past decade, the Canadian aluminum and steel industries have performed well and remained internationally competitive. The major producers have increased capacity cautiously and have managed to operate at generally high levels of plant utilization. Managements have followed a policy of not diversifying far from the two base industries.

Firms in both industries have actively adopted new process technologies developed elsewhere, and have engaged in a moderate amount of research and development associated with both new products and processes. In addition, managements have adopted state-of-the-art management practices designed to improve the productivity performance of their firms.

Provincial governments have pursued energy policies to allow aluminum producers to remain internationally competitive. Given the current problems facing the Canadian steel industry, is there a policy role to be played by Canadian provincial governments here as well? With the

notable exception of the two provincial Crown corporations, the Canadian steel industry favours a "hands-off" industrial policy approach, relying instead on tax incentives and commercial policy to stimulate private enterprise, on domestic market opportunities, and on fair access to the U.S. market. What it does not want is an interventionist set of industrial policies which leads to the funding of weak companies.

Keeping foreign markets open to exports of steel and aluminum has been an important contribution of the federal government. The relationship between the industries and the federal government can be characterized as open consultation and can be expected to continue, in the light of anticipated trade discussions with the United States.

Given the current excess steel capacity in Canada, its financial implications for the industry, and the rather grey outlook for the near future, any move to invest significant funds in the modernization and expansion of the two provincial Crown corporations would have to be seriously questioned. At this time, inefficient and outdated operating facilities in the United States and Europe are being closed. The provincial and federal governments would be well advised to consider other industrial and job-creating options to solve the local employment and related social problems, rather than propping up these two Crown corporations.

In sum, the combination of sound management strategies and generally sound government policies have influenced favourably the performance of the two industries. Any move away from trade liberalization in Canada or abroad would be harmful to both industries, and should continue to be resisted.

Notes

This paper was completed in August 1984.

1. See United States, Department of the Interior, Bureau of Mines, *U.S. Minerals Year Book 1980* (Washington, D.C.: U.S. Government Printing Office, 1980), p. 74.
2. All comparisons in this paragraph are based on data from the *U.S. Minerals Year Book* and differ slightly from those in Table 5-1.
3. See Mining Journal, *Mining Annual Review*, (London, 1971) p. 77, and (1981), p. 58.
4. See United Nations, *Yearbook of International Trade Statistics* (New York, 1980), p. 158, and (1982), p. 158.
5. Data supplied by Alcan.
6. Data supplied by Canadian Reynolds.
7. In 1983, Alcan again emphasized the U.S. market with its acquisition of Atlantic Richfield's aluminum assets in the United States.
8. Data supplied by Alcan.
9. Data supplied by Alcan.
10. See Commodities Research Unit, *Aluminum May 1983, Quarterly Report Service* (New York), p. 60.
11. See *Journal of Commerce* (November 14, 1983), p. 2.
12. Data supplied by Alcan.

13. Data supplied by Alcan. At Reynolds in Baie-Comeau, labour productivity is estimated to range from 93 to 117 tonnes per employee based on cumulative production of 1,827,000 tonnes (1970–82), an average of 140,000 tonnes a year and a work force ranging from 1,200 to 1,500 employees, according to data supplied by Canadian Reynolds.
14. See *Financial Post* (May 5, 1984), p. 28.
15. See Arco Aluminum and Government of Newfoundland and Labrador, *Newfoundland Greenfield Aluminum Smelter*, Joint Feasibility Study, Summary Report, April 1983. Since making this study Arco has sold its U.S. aluminum smelting and most of its fabricating facilities to Alcan.
16. See International Iron and Steel Institute, *World Steel in Figures 1983*, (Brussels), p. 3.
17. Ibid., p. 4.
18. The iron and steel sector is covered in SIC 291, Iron and Steel Mills, and includes the production of pig iron, steel ingots, steel castings, and primary rolled products.
19. See Statistics Canada, *Industrial Organization and Concentration in the Manufacturing, Mining and Logging Industries of Canada, 1980*, cat. no. 31–402 (Ottawa: Statistics Canada).
20. For a discussion of these approaches, see Porter (1980), pp. 34–40.
21. Notable exceptions occurred in 1982 and 1983 when both Stelco and Algoma experienced losses.
22. The exception is Canadian Pacific, which controls Algoma and Cominco.
23. For a detailed examination of the importance of ferrous scrap, see McMullen and Pope (1982).
24. Statistics Canada, *Employment, Earnings and Hours*, cat. no.72–202 (Ottawa: Statistics Canada).
25. Ibid.; the industrial aggregate is $390; the manufacturing average is $434; and the iron and steel industry average is $577.
26. Reported in *The Wall Street Journal* (May 17, 1983), ("Steel's Management Has Itself to Blame," by T.F. O'Boyle).
27. See Prehearing Brief of the Canadian Steel Industries Committee, Before the United States International Trade Commission, Inv. No. TA-201-51, Washington, D.C., May 3, 1984, p. 10.
28. See Algoma, Atlas, Dofasco and Stelco, *The Canadian Steel Industry and the Future of the Automotive Industry in Canada*, a submission to the Minister of Industry, Trade and Commerce (Ottawa, April 1983), p. 14.
29. Ibid.

Bibliography

Aluminum

Alcan. 1981, 1982. *Annual Report*. Montreal.

________. 1983. "Kemano Completion Project." *A Handbook for the News Media*. Montreal.

Arco Aluminum and Government of Newfoundland and Labrador. 1983. "Newfoundland Greenfield Aluminum Smelter." Joint Feasibility Study, Summary Report. St. John's.

Australian Mineral Economics Ltd. 1981. *Aluminum*. Vols. 1 and 2. Sydney.

Butcher, G. 1982. *Aluminum: The International Perspective*. London: Financial Times.

Chase Econometrics. 1983. *World Aluminum Outlook*. New York.

Commodities Research Unit. 1983. *Aluminum May 1983: Quarterly Report Service*. New York.

International Primary Aluminum Institute. Annual. *Statistical Summary*. London.

Litvak, I.A., and C.J. Maule. 1975. "Cartel Strategies in the International Aluminum Industry." *Antitrust Bulletin* 20 (Fall): 641–63.

———. 1982. "The Impact of the International Bauxite Agreement." *Canadian Journal of Development Studies* 3 (no. 2).

Metal Bulletin, Inc. 1980. *Proceedings of First International Aluminium Congress held in Madrid*. London.

Organisation for Economic Co-operation and Development. 1973. *Problems and Prospects of the Primary Aluminum Industry*. Paris: OECD.

———. 1983. *Aluminum Industry: Energy Aspects of Structural Change*. Paris: OECD.

Peterson, G.R., and S.J. Arbelbide. 1983. *Aluminum Availability: Market Economy Countries*. U.S. Department of the Interior, Bureau of Mines, Information Circular 8917. Washington, D.C.: U.S. Government Printing Office.

Potter, W.J., and R.J. Slaymaker. 1983. "Changing Patterns in Aluminum." Presentation to the Canadian Institute of Mining and Metallurgy Annual General Meeting, Winnipeg, April 30.

Rogers, S. 1978. "Economic Trends in the Aluminum Industry." Ph.D. diss., University of Colorado, Colorado School of Mines.

United States. Department of the Interior. Bureau of Mines. 1983. *Aluminum*. Mineral Commodity Profiles. Washington, D.C.: U.S. Government Printing Office.

Steel

Algoma, Atlas, Dofasco, and Stelco. 1983. "The Canadian Steel Industry and the Future of the Automotive Industry in Canada." A submission to the Minister of Industry, Trade and Commerce. Ottawa.

American Iron and Steel Institute. Annual. *Directory of Iron and Steel Works of the United States and Canada*. Washington, D.C.: The Institute.

———. Annual. *Statistical Reports*. Washington, D.C.

———. 1981. *Steel at the Crossroads: One Year Later*. Washington, D.C.: The Institute.

American Metal Market Co. Annual. *Metal Statistics: The Purchasing Guide of the Metal Industries*. New York.

Barnett, D.F. 1980. *Labor Productivity Trends in the U.S. Steel Industry*. Economic Papers. Washington, D.C.: American Iron and Steel Institute.

Barnett, D.F., and L. Schorsch. 1983. *Steel*. Cambridge, Mass.: Ballinger.

Canada. Department of External Affairs. 1983. *A Review of Canadian Trade Policy*. Ottawa: Minister of Supply and Services Canada.

Canadian Steel Industry Research Association. 1983. *The Canadian Steel Industry*. Toronto.

Crandall, Robert. 1981. *The U.S. Steel Industry in Recurrent Crisis*. Washington, D.C.: Brookings Institution.

Daly, D.J. 1984. "Productivity and Cost Competitiveness in the Canadian Economy." A brief to the Royal Commission on the Economic Union and Development Prospects for Canada.

Deiley, Richard L., ed. 1981. "The World Steel Industry: Into and Out of the 1980s." *IISS Commentary*. Green Brook, N.J.: Institute for Iron and Steel Studies.

Hogan, W.T. 1983. *World Steel in the 1980s*. Lexington, Mass.: Lexington Books.

Keeling, B. 1982. *The World Steel Industry*. Special Report 128. London: The Economist Intelligence Unit Limited.

Labee, E.J., and N.L. Samways. 1982. "Developments in the Iron and Steel Industry, U.S. and Canada: 1981." *Iron and Steel Engineer* 59 (February): D1–D34.

Litvak, I.A., and C.J. Maule. 1977. *Corporate Dualism and the Canadian Steel Industry*. Ottawa: Minister of Supply and Services Canada.

McMullen, M.K., and J.C. Pope. 1982. *The Canadian Ferrous Scrap Industry*. Ottawa: Department of Industry, Trade and Commerce.

Organisation for Economic Co-operation and Development. 1981. *The Steel Market in 1980 and the Outlook for 1981*. Paris: OECD.

Porter, M.E. 1980. *Competitive Strategy*. New York: Free Press.

Reich, Robert B. 1983. *The Next Frontier*. New York: Times Books.

Scherer, F.M. et al. 1975. *The Economics of Multi-Plant Operation*. Cambridge, Mass.: Harvard University Press.

Schottman, F.J. 1983. *Iron and Steel*. U.S. Department of the Interior, Mineral Commodity Profile. Washington, D.C.: U.S. Government Printing Office.

Stelco. 1975. "Submission of the Steel Company of Canada, Limited, to the Royal Commission on Corporate Concentration." Ottawa.

United States. Congress. Office of Technology Assessment. 1980. *Technology and Steel Industry Competitiveness*. Washington, D.C.: U.S. Government Printing Office.

6

Technology Diffusion
A Survey of Canadian Evidence and Public Policy Issues

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The purpose of this paper is to survey the evidence on the diffusion of technology, particularly as it relates to Canada, and to describe recent policy measures bearing on the diffusion of technology to and within Canada. Our discussion of technology diffusion studies relating to other countries is brief, both because there is a great deal of Canadian material to cover and because much of the literature has been surveyed by Gold (1981), Kamien and Schwartz (1982), Stoneman (1983) and Mansfield (1985).

Technology diffusion is simply the spread of technology from its source — the inventor or innovator — to its users. This spreading process is often quite slow, with lags occurring between the time a technology appears (or is patented) and the time it is first commercialized, and between the first and second commercialization, the second and third or later commercializations.

The pattern of adoptions of a new technology over time can be studied from a number of different perspectives. One can study the diffusion of a new technology within the firm. An example would be the spread of diesel locomotives within various railway companies (Mansfield, 1968). A more common perspective is that of the industry, wherein the spread of a new technology can be measured over time. Examples would be the spread of hybrid corn among corn growers (Griliches, 1957) or the spread of electronic data processing within the insurance industry (Globerman, 1984). The rate at which an innovation spreads within an industry is called an intra-industry diffusion rate.

When either the firm or the industry is used as a unit of observation, it can also be determined whether there are systematic differences between the characteristics of firms or industries which adopt early or late and diffuse quickly or slowly. Were the first firms to use numerically controlled (NC) machine tools bigger or were their managers better educated than those of the later adopters (Globerman, 1975)? Were the more competitive industries those in which NC machine tools spread the fastest (Romeo, 1975)? Diffusion within an industry can also be examined on a geographic or jurisdictional basis. The characteristics of early and late adopting or fast and slow diffusing jurisdictions or regions can then be compared. A good example of this type of work is that of Oster and Quigley (1977) on innovations in the building industry.

Another perspective is that of the national economy. The nation as a unit of observation can be used in measuring the speed at which technology diffuses internationally and in comparing the characteristics of early and late adopting countries or countries with fast and slow internal diffusion rates (Swann, 1974; Nasbeth and Ray, 1974; Mansfield et al., 1982). It was the comparison of intra-industry diffusion rates in Canada with those (for the same technology) in other countries which led Daly and Globerman (1976) to argue in favour of a greater emphasis on policies to assist diffusion.

Inter-industry diffusion can be examined from a national perspective by measuring the flow of technology from source to using industries. Recent attempts to measure these flows (Hartwick and Ewen, 1983; Postner and Wesa, 1983; Seguin-Dulude, 1982) can be viewed as having been motivated by a desire to find the sectors which are in some sense "responsible" for economy-wide (total factor) productivity growth. Associated with this has been an attempt to redefine a high-tech industry as one which either generates or applies new technology. Finally, inter-industry diffusion studies can tell us something about the spillover or externality associated with research and development (Scherer, 1982a; Griliches and Lichtenberg, 1984).

The study begins with a short discussion of some theoretical problems associated with discerning the pattern of diffusion over time. It then proceeds to the discussion of the evidence on intra- and inter-industry diffusion, both national and international, and to an examination of the diffusion process from government to industry. This is followed by a summary and assessment of the policy debate on each of these topics and a short concluding section.

Intra-Industry Diffusion

In this section, we review the literature on the diffusion of technology within industries. In particular we examine:

- the theory underlying the decision to adopt a certain technology and the measurement of its diffusion;
- the evidence on the rate of diffusion in Canadian service and manufacturing industries and in comparable foreign industries; and
- the evidence on the characteristics of firms or organizations which adopt early and of industries in which innovations are diffused quickly.

Theoretical Background

The decision to acquire a new technology is an investment decision and as such depends ultimately on profitability. As Stoneman (1983) shows, profit-maximizing investment behaviour in the presence of adjustment costs can generate an adoption pattern (within the firm) such that the proportion of output produced with a new technology follows an S-shaped curve (a sigmoid) over time. This pattern need not result if the price of the innovation changes over time or if there is strategic interaction at the market level among the various potential adopters (Reinganum, 1981, 1983).

There are a number of S-shaped curves which may be used to describe diffusion patterns. Two of the most common are the logistic curve and the Gompertz curve. As demonstrated by Dixon's (1980) reassessment of Griliches' pioneering work (1957) on the diffusion of hybrid corn, the inferences drawn regarding the rate of diffusion depend on the particular S-curve assumed for empirical purposes.[1]

Once an S-curve has been chosen, there are operational problems associated with its estimation. In particular, estimates of the rate of diffusion depend on what is assumed to be "full" diffusion. In most cases, a technology is not adopted by 100 percent of the firms classified to a particular industry. Different estimates of the diffusion rate are obtained depending on whether it is assumed that the maximum proportion observed or 100 percent or something in-between constitutes full adoption. Since "full" adoption will vary across industries and countries, inter-industry and international comparisons of diffusion rates are problematic.

The problems encountered in the international comparison of national diffusion rates are illustrated in the example of the diffusion of the basic oxygen process in Canada and the United States. Two Ph.D. theses have been written attempting to explain the relatively early adoption of the basic oxygen process in Canada and its quick diffusion in the years immediately following its adoption (De Melto, 1970; Bauman, 1971). Although the role of scale is agreed upon by all (Economic Council of Canada, 1983, p. 55; Oster, 1982, p. 52), the oligopolistic nature of the U.S. industry and the progressiveness and exposure to international

competition of the Canadian industry are also adduced as explanations. The impressions of backwardness of the U.S. steel industry and progressiveness of the Canadian one were based on observations taken at a relatively early stage of the diffusion process in both countries. If judgments were formed on the basis of diffusion curves estimated with ten years' worth of additional data, would they differ?

The answer is given in Table 6-1 and it would have to be yes. The earlier assessments of the comparative records of the U.S. and Canadian steel industries were based on the diffusion of the basic oxygen process from 1955 until the late 1960s. A logistic curve estimated with data running up to the late 1970s implies that the average annual diffusion rate has been twice as high in the United States as in Canada. This is not to say that the Canadian industry is not progressive. Litvak and Maule, in their study in this volume, make a persuasive case that it is. Nor is it an attempt to discredit two excellent studies of the early history of basic oxygen in North America. It is simply to demonstrate that inferences can vary with both the proportion and the stage of the diffusion process observed.

Our results also serve to illustrate the other points we have made. We assume two alternative "full" diffusion proportions — 100 percent and 70 percent. It is evident that the estimated diffusion rate depends on which assumption is made. In this case, the lower the "full" diffusion proportion that is assumed, the lower the estimated diffusion rate.[2] The problem is thus one of deciding what full diffusion is for each country examined. This can be determined with certainty only after the next generation of technology has begun to be adopted.

Finally, the estimates reported in Table 6-1 differ markedly depending on whether the estimation technique used is ordinary or weighted least squares. The latter is the appropriate estimation technique but it was not used in a number of early studies.[3]

Intra-Industry Diffusion Rates: Canada Versus Other Countries

Virtually all of the work comparing the rate of diffusion of a given technology within Canadian industry with the rate of diffusion in the same industry in the United States or other foreign countries has been done by Globerman (1975a, 1975b, 1976, 1981, 1984). A summary of the comparisons he makes and his conclusion in each case is presented in Table 6-2.

In general, Globerman finds that adoption of new technologies proceeded more slowly in Canada than in the United States (or, in one case, Europe). He is able to draw relatively firm conclusions for the three manufacturing industries examined. In the case of numerically controlled (NC) machine tools in the tool and die industry, there was both an

TABLE 6-1 Basic Oxygen Steel Logistic Diffusion Curves, Canada–United States, 1955–77

	United States				Canada			
Dependent variable	$\ln[\pi_i/(1-\pi_i)]$		$\ln[\pi_i/.7-\pi_i)]$		$\ln[\pi_i/(1-\pi_i)]$		$\ln[\pi_i/.7-\pi_i)]$	
Independent variables								
Intercept (years)	−6.216	−5.313	−6.435	−5.265	−2.802	−2.103	−3.077	−1.86
Time (years)	.7225	.283	.6299	.8363	.3107	.1028	.2416	.1375
	(15.107)	(18.017)	(11.867)	(29.3)	(11.36)	(10.7)	(10.05)	(11.003)
R^2	.9117	.9363	.8641	.9748	.8526	.8376	.8196	.8451
Number of observations	23	23	23	23	23	23	23	23
Method[a]	WLS	OLS	WLS	OLS	WLS	OLS	WLS	OLS

Source: Estimates by the authors.

a. Both weighted least squares and ordinary least squares were used. For WLS, the weight is defined as $w_i^{-.5}$ *where* $w_i = \pi_i/[\pi_i(1-\pi_i)]$.
t = statistics in parentheses

TABLE 6-2 International Comparisons of Intra-Industry Diffusion Rates

Industry	Technology	Time period	Countries	Author's Interpretation Data
Tool and die	NC machine tools	1961–72 1961–68	Canada United States	"The rate of diffusion in the U.S. industry was roughly four times the rate in the Canadian industry" (1975b, p. 434)
Carpet weaving	tufting machines	1953–71 1952–63	Canada United States	"The speed of adoption was . . . slower in Canada" (1975a, p. 196)
Paper	special presses	1966–72 1968	Canada Europe	"Inter-firm diffusion apparently proceeded at a faster rate in Europe" (1976, p. 7)
Libraries	EDP	1966–71	Canada United States	"Any difference in early adoption not marked" (1971, p. 13)
Hospitals	EDP	1974–78 1974–78	Canada United States	"Differences between Canadian and U.S. adoption ratios are sufficiently large" (1981, p. 20) (in favour of United States)
Department and variety stores	EDP	1968 1968	Canada United States	"Slower rate of adoption in Canada is suggestive . . . but not conclusive (1981, p. 36)
Retailers and wholesalers	EDP	1973–78 1978	Canada United States	"Little information to facilitate comparison" (1981, p. 318)
Insurance	EDP	1956–62 1956–62	Canada United States	"U.S. was first off the mark to automate in the mid-1950s, by 1962 there was no apparent difference" (1983, p. 50)

Source: S. Globerman, "Technological Diffusion in the Canadian Carpet Industry," *Research Policy* 4 (1975): 190–206; idem., "Technological Diffusion in the Canadian Tool and Die Industry," *Review of Economics and Statistics* 57 (1975): 428–34; idem., "New Technological Adoption in the Canadian Paper Industry," *Industrial Organization Review* 4 (1976): 5–12; idem., *The Adoption of Computer Technology in Selected Canadian Services Industries*, Economic Council of Canada (Ottawa: Minister of Supply and Services Canada, 1981); and idem., *The Adoption of Computer Technology by Insurance Companies* (Ottawa: Supply and Services Canada, 1983).

international diffusion lag (first adoption was later in Canada than in the United States and other countries — see Table 6-3) as well as a domestic diffusion lag. Specifically, given the use of NC machine tools by 25 percent of the eligible firms in both countries, the proportion of users would have increased by 10 percentage points a year in the United States and by under 2.5 percentage points per year in Canada.

In the case of tufting machines, there was again both an international and a domestic diffusion lag. In the case of special presses, there was no international diffusion lag but there was an "apparent" domestic lag.

In his more recent studies of the diffusion of electronic data processing (EDP) in five service industries, Globerman is able to draw a firm conclusion in one case. Diffusion of EDP was slower in Canadian hospitals than in U.S. hospitals. Approximately 65 percent of U.S. hospitals were using EDP in some fashion in 1979 and only 30 percent of Canadian hospitals in 1978 (1981, pp. 20–21). In the other cases involving libraries, department and variety stores, retailers and wholesalers and insurance companies, either the differences were not large or the data did not permit a firm conclusion.

Data limitations are severe here. In only one case (NC machine tools) did Globerman have sufficient data to estimate a diffusion curve. In some cases (department stores, retailers and wholesalers), comparisons are based on one observation for each country. In cases such as these, a low proportion of Canadian organizations using a particular technology is consistent with all combinations of international and domestic diffusion lags except early first adoption and fast diffusion (that is, it could be a consequence of late first adoption but fast domestic diffusion, or of early first adoption but slow domestic diffusion, and so on). Each combination implies a different policy response.[4]

The slower diffusion of NC machine tools in the Canadian tool and die industry is attributed by Globerman (1975b) to differences in competition, information availability, proximity to suppliers, wage rates and firm size between the two countries. In their investigation of the diffusion of the same technology in six countries, Nasbeth and Ray (1974) find that diffusion rates depended on wage levels, financing possibilities, management and union attitudes and the "condition of the market."

Characteristics of Early Adopters: Canadian Evidence

As Table 6-3 indicates, the Canadian evidence is that foreign ownership tends to increase the probability of early adoption of both special presses in the paper industry and NC machine tools in the tool and die industry. The probability of early adoption of NC machine tools tends to increase both with R&D intensity and firm size in the tool and die industry but, in the case of the latter, not continuously.[5]

TABLE 6-3 Factors Determining the Probability of Early Adoption of a Specific Technology in Manufacturing Firms

Technology	Special Presses	Numerical Control	Numerical Control
Industry	paper industry (Canadian)	tool and die (Canadian)	tool and die (United States)
Dependent variable	probability of adopting by 1969	probability of adopting by 1972	probability of adopting by 1970
Independent variables	foreign ownership (+)[a]	foreign ownership (−)	
	R&D (−)	R&D(+)[b]	
		age of president of firm (+)[a]	age of president of firm (−)
		education of president (+)	education of president (+)[b]
		firm size (number of employees in 1972) (+)[a]	firm size (number of employees in 1972) (+)[a]
	average age of machine in 1965 (−)		
	number of machines operated in 1965 (−)		
	proportion of newsprint to total output in 1965 (+)[a]		
			years the manager knew of NCM(+)
			number of people in firm who had to approve decision to adopt (−)[b]

Source: S. Globerman, "Technological Diffusion in the Canadian Tool and Die Industry," *Review of Economics and Statistics* 57 (1975): 428–34; idem, "New Technology Adoption in the Canadian Paper Industry," *Industrial Organization Review* 4 (1976): 5–12; and A.A. Romeo, "Inter-industry and Inter-firm Differences in the Role of Diffusion of an Innovation," *Review of Economics and Statistics* 57 (August): 311–19.

a. Statistically significant at 5 percent level.
b. Statistically significant at 10 percent level.

Characteristics of early adopters in the service industry are given in Table 6-4. The probability of early adoption increases with organization size in three cases. Various indexes of the receptiveness of management to change and of organizational slack were statistically significant in two cases and one case, respectively.

In general, although the direction of causality is not always clear, early adoption tends to be facilitated by larger size, R&D expenditures, foreign ownership, and various measures of organizational receptivity to change. There is not much support, however, for the hypothesis that early adoption would be facilitated by more or better management education. In this regard, Globerman (1985) concludes:

> While a few available studies provide direct evidence that more educated managers are quicker to adopt new technology than their less educated counterparts, a substantial proportion provide only indirect support for the adaptability hypothesis, or (in fact) no support at all.

While management education may have little influence on diffusion rates, other forms of education or the education levels of other parties in the diffusion may be relevant. Some findings in this regard are discussed in the next section.

Determinants of Intra-Industry Diffusion Rates and Characteristics of Early Adopters: Foreign Evidence

Major foreign studies in this area include one by Mansfield (1968) which examines inter-industry differences in intra-industry diffusion rates. Mansfield finds that the diffusion rate tends to be greater: (a) the more profitable the innovation; (b) less durable its capital stock (for embodied innovations); and (c) the greater its rate of sales growth and capacity utilizaton.

Romeo (1975) compares the respective rates of diffusion of NC machine tools in ten industries and finds that the diffusion rate within industries is an increasing function of average firm size, the average profitability of the innovation, average R&D and the number of firms in the industry.

Rappoport (1978) and Russell (1979) study the adoption of EDP and other innovations (intensive care, radioisotopes, and so on) in U.S. hospitals. Both find that hospital size is the major factor contributing to early adoption.

Oster (1982) investigates the determinants of the probability of early adoption of the basic oxygen process by U.S. steel firms and find that it is greater when the cost saving to the firm involved was greater, especially for smaller firms.

Hannan and McDowell (1984) investigate the determinants of the probability of early adoption of automatic teller machines by U.S.

TABLE 6-4 Factors Determining the Probability of Early Adoption of Electronic Data Processing Technologies in Service Firms or Organizations

	Libraries	Ontario Hospitals	Retail Grocery	Department and Variety Store	Insurance
Dependent variable	probability of adoption by 1974	probability of adoption by 1974	probability of adoption at head office by 1974	probability of adoption at head office by 1974	probability of adoption by 1969
Independent variables:					
Size	(+)[a]	(+)[a]	(+)	(+)[b]	(+)[a]
Index of market share dispersion	(−)[b]	(+)[a]			
Management's receptivity to change	(−)[a] ratio of microfilms, microfiche and microcassette to all volumes	(+/−)[a] = 1 if hospital converted to metric; 0 otherwise	(+)[a] = 1 if scanning equip. was used; 0 otherwise	(+) = 1 if computerized chequing authorization was used; 0 otherwise	
Organizational slack[1]	(−)[a]	(+/−)			
Other variables	(+) labour saving	(−) Religious dummy = 1 if hospital had religious affiliation; 0 otherwise	(+)[a] vertical integration variable	(+) vertical integration variable	(−)[a] = 1 if U.S. owned; 0 otherwise (−)[b] = 1 if foreign owned (excluding United States); 0 otherwise

	(−) demand for library services	(+) age of hospital	(+/−) interregional differences characterized by four regional dummies	(+/−) interregional differences characterized by four regional dummies	
		(+/−) whether hospital contained a medical school			(+) whether firm handled multiple policies or not (−) growth variable

Source: S. Globerman, *The Adoption of Computer Technology in Selected Canadian Service Industries*, study prepared for the Economic Council of Canada (Ottawa: Minister of Supply and Services Canada, 1981); idem. "The Adoption of Computer Technology by Insurance Companies." (Vancouver: Simon Fraser University, School of Business, 1984) mimeographed.

a. Statistically significant at 5 percent level

b. Statistically significant at 10 percent level

c. Organizational slack variable for libraries was percentage growth in salary expenditure minus percentage growth in total library volumes, also the ratio of total professional librarians to total full time staff in 1970–71. For hospital the slack variable was percentage growth in hospital admissions minus percentage growth in personnel over 1970–74.

banks. They find that early adoption is more likely (a) for larger banks; (b) the greater the retail orientation of the bank; (c) the higher the wage rate prevailing in the market served by the bank; (d) if the bank is owned by a holding company; and (e) if branching is not allowed but off-premise automatic tellers are.

Wozniak (1984) investigates the influence of a farmer's education level, experience and contact with extension services, and of farm size on the probability of adopting the feed additive monensin sodium (AMS) and the complementary technology of implanted growth hormones (IMPT) prior to 1976. Using a methodology which recognizes the simultaneity of the two adoption decisions, Wozniak finds that farmer education increases the probability of AMS adoption but exerts no direct influence on IMPT adoption.[6] The marginal effect of education on the probability of AMS adoption becomes negative, however, after 11.6 years of education. Wozniak finds that experience exerts no effect on the probability of adopting either technology, while the frequency of contact with extension workers (which should also be jointly dependent) has a positive direct effect on the probability of AMS adoption. Farm size exerts a positive effect on both probabilities of adoption until the farm sizes of approximately 900 to 1000 cattle slaughtered per year are reached.

Intra-industry diffusion can be measured on a geographic as well as on a firm (or organization) basis. Oster and Quigley (1977) take this approach in their analysis of the diffusion of innovative building techniques. They find that a jurisdiction is more likely to allow these innovations: (a) the better educated its chief building official; (b) the smaller the proportion of unionized workers; (c) the greater the demand pressure on the housing market; and (d) the larger the average size of building firms in the jurisdiction (p. 374).[7]

Some General Conclusions

It is stating the obvious to say that an innovation diffuses faster the more profitable it is and that it is adopted first by the firms finding it the most profitable. Profitability depends variously on wage rates (for labour-saving innovations), output mix, the nature of the existing production technology and the durability of productive assets.

Firm or organization size often, although not always, exerts a positive influence on the speed of adoption. This positive influence does not necessarily prevail across all organization sizes. To the extent that it does exist, it may reflect some or all of: (a) the ability to diversify risk; (b) economies of scale in information gathering (shopping); and (c) the scale bias of the innovation in question. The latter factor is emphasized by Globerman (1981) in his assessment of the role of size.

Whatever the basis for its influence, the size effect can be quantitatively important. Our calculations imply that nearly half the differ-

ence between the average lag in the adoption of NC machine tools in Canada and the United States would be eliminated if Canadian firms were as large as U.S. firms.[8]

The relevance of other factors depends on the circumstances. A past history of technical receptiveness is important (but it is not an explanation). R&D can be important but may be either a cause or a consequence of early adoption. The competitive environment can matter. Both Globerman (1981, p. 5) and Kamien and Schwartz (1982, p. 102) conclude that there tends to be a negative relationship between the diffusion rate and industrial concentration. Foreign ownership can contribute to early adoption and, perhaps more importantly, does not seem to have hindered it.

Basic education can matter, but more is not always better. Moreover, as the more sophisticated representations of the diffusion process are now showing, more education can reduce the marginal effects of other factors such as experience and the activities of extension services on the speed of diffusion. These features of the environment must be examined together before policy conclusions can be drawn.

Management education may not matter, but it is hard to disentangle its influence from that of firm size. Management incentives do matter, as indicated by the differences between private and public sector U.S. hospitals cited by Globerman (1981, p. 20).

The education of regulatory officials also appears to matter, as does the regulatory process itself. Interest group pressures have hindered the diffusion of new technologies, at least in the building industry. Olson (1982) argues that this will occur with increasing frequency as more interest groups become entrenched in our society.

International Diffusion

A good discussion of the recent literature appears in the study by Mansfield in this volume. The purpose of this section is to provide some complementary material on the measurement and magnitude of international diffusion lags, and on the effect of national characteristics and policies on international diffusion lags.

International Diffusion Lags

Evidence on international diffusion lags can be derived from large sample surveys such as those conducted by De Melto et al. (1980), Mansfield and Romeo (1980), and Vernon and Davidson (1979), or from collections of studies of individual technologies such as that of Nasbeth and Ray (1974).

The evidence from the large databases is summarized in Table 6-5. The diffusion lag of the *i*th country is defined as the number of years between

the first commercial use of an innovation anywhere in the world and its first commercial use in the *i*th country.

The data reported in Table 6-5 have two major implications. First, the mean transfer lag is much shorter for intra-corporate transfers than for arm's-length (market) transfers. The reasons for this are discussed later in this paper. Second, given the transfer mode, the diffusion lag to Canada was never slower (on average) than to other developed countries. Indeed, in some cases — such as (a) the comparison of intra-corporate transfers to Canada and Europe using the Vernon-Davidson data; and (b) the comparison of arm's-length transfers to developed countries using the Economic Council (1983) and Mansfield and Romeo (1980) data — the diffusion lag to Canada was much shorter.

International diffusion lags have also been measured in individual case studies.[9] Nasbeth and Ray (1974) measure diffusion lags for a number of technologies and countries, not including Canada. Using several sources, we are able to calculate the diffusion lag to Canada for some of the technologies studied in their report. The results are given in Tables 6-6 and 6-7. The United States is not included in the table by Nasbeth and Ray upon which this work is based. As a consequence, absolute diffusion lags are understated in some instances. Inferences can be made, however, as to relative diffusion lags.

The tables indicate that long diffusion lags are not or at least were not uncommon. The first Canadian adoption was relatively early in the cases of basic oxygen furnaces, hot wide strip mills and special presses. It was relatively late in the cases of continuous casting and shuttleless looms. In the other cases, the diffusion lag to Canada was close to the mean lag.

Differences in diffusion lags can often be attributed to technology-specific factors. The suitability of the basic oxygen process to relatively small producers (Oster, 1982, p. 52) may have contributed to its early adoption in Canada. The large minimum scale associated with the float glass process (Nasbeth and Ray, 1974, p. 211) may explain its relatively late transfer to Canada. The relatively small size of the Canadian market may also have been relevant in such industry processes as continuous casting. There may also have been other general factors at work, such as the absence of information. This receives further discussion below.

A final case study of note is of synthetic rubber (Swann, 1973). In this case, initial adoption in Canada came in 1940, one year after adoption by the leader (the United States) and approximately ten years earlier than adoption in most European countries. This lag pattern can be attributed in large measure to the strategic importance of synthetic rubber during World War II.

TABLE 6-5 Alternative Estimates of the Mean International Diffusion Lag, 1960–79

	Mean Lag	Observations
	(years)	
Multinational Enterprise Database		
Canada		
Intra-corporate	6.93	115
Arm's length	10.00	7
Both	7.11	122
Europe		
Intra-corporate	10.27	340
Arm's length	10.86	116
Both	10.42	456
Rest of the World		
Intra-corporate	11.01	323
Arm's length	12.40	233
Both	11.70	556
Economic Council database		
Canada		
Intra-corporate	5.80	37
Arm's length	8.80	19
Both	6.94	56
Mansfield and Romeo		
Overseas developed countries[a]		
Intra-corporate	5.8	27
Licensing/joint ventures	13.1	26
Less developed countries		
Intra-corporate	9.8	12

Source: Estimates made by the authors of this paper using the Multinational Enterprises Database (see R. Vernon and W.H. Davidson, "Foreign Production of Technology-Intensive Products by U.S.– based Multinational Enterprises," Working Paper (Boston: Harvard University Graduate School of Business, 1977)) and the Economic Council Database (see D.P. De Melto, K. McMullen and R. Wills, "Innovation and Technological Change in Five Canadian Universities," Economic Council of Canada Discussion Paper 176 (Ottawa: The Council, 1980); E. Mansfield and A. Romeo, "Technology Transfer to Overseas Subsidiaries by U.S.–based Firms," *Quarterly Journal of Economics* (December 1980): pp. 737–50.

a. Including Canada.

TABLE 6-6 Year of First Adoption of Selected Processes, Seven Countries

Processes	Austria	France	Italy	Sweden	United Kingdom	West Germany	Canada
NC machine tools	1963	1957	1960	1958	1955	1962	1961
Special presses	1966	1965	1965	1963	1964	1965	1963
Tunnel kilns	1957	1949	1951	1948	1902	1959	n.a.
Basic oxygen steel	1952	1956	1964	1956	1960	1957	1954
Float glass	—	1966	1965	—	1958	1966	1967
Gibberellic acid	—	1966	—	1959	1959	—	1964
Continuous casting	1952	1960	1958	1963	1960	1954	1965
Shuttleless looms	1961	1953/4	1960	1957	1958	1954	1962
Plate cutting methods	—	1960	1962	1950	1950	1953	n.a.
Automatic transfer lines	—	1947	1950	1955	1947	1954	n.a.
Hot wide strip mills	1955	1960	1964	1962	1958	1965	1954

Source: L. Nasbeth and G. Ray, eds. *The Diffusion of New Industrial Processes* (London: Cambridge University Press, 1974), p. 17; J. Aylen, "Innovation in the British Steel Industry," in *Technical Innovation and British Economic Performance*, edited by K. Pavitt (London: Macmillan, 1980), pp. 200–34; H.G. Baumann, "The Diffusion of Technology and International Competitiveness: A Case Study of the Canadian Primary Iron and Steel Industry," Ph.D. diss., Queen's University, Kingston, 1971; and discussions with officials of the Department of Regional Industrial Economic Expansion.

TABLE 6-7 Time Lag After First Adoption, Seven Countries

Processes	Austria	France	Italy	Sweden	United Kingdom	West Germany	Canada	Mean Lag	Mean minus Canada[a]
NC machine tools	8	2	5	3	0	7	6	5.2	−0.8
Special presses	3	2	2	0	1	2	0	1.7	1.7
Basic oxygen steel	0	4	12	4	8	5	2	5.8	3.8
Float glass	n.a.	8	7	n.a.	0	8	9	8.0	−1.0
Gibberellic acid	n.a.	7	n.a.	0	0	n.a.	5	4.0	−1.0
Continuous casting	0	8	6	11	8	2	13	8.0	−5.0
Shuttleless looms	7	0	6	3	4	1	8	4.8	−3.2
Plate cutting methods	n.a.	10	12	0	0	3	n.a.	8.1	n.a.
Automatic transfer lines	n.a.	0	3	8	0	7	n.a.	4.5	n.a.
Hot wide strip mills	1	6	10	8	4	11	0	6.7	6.7

Source: L. Nasbeth and G. Ray, eds. *The Diffusion of New Industrial Processes* (London: Cambridge University Press, 1974), p. 17; J. Aylen, "Innovation in the British Steel Industry," in *Technical Innovation and British Economic Performance*, edited by K. Pavitt (London: Macmillan, 1980), pp. 200–34; H.G. Baumann, "The Diffusion of Technology and International Competitiveness: A Case Study of the Canadian Primary Iron and Steel Industry," Ph.D. diss., Queen's University, Kingston, 1971; and discussions with officials of the Department of Regional Industrial Economic Expansion.

a. Negative values imply slower than average adoption by Canada.

An alternative way of measuring the international diffusion lag is in terms of the number of prior adoptions. A nation may, for example, adopt a technology only two years after its first world use but be the tenth nation to do so. This may imply something about the potential rents available from the adoption of this technology. Also, given the apparent compression of the diffusion process, it is useful to measure it in two dimensions — years since first world use and number of prior foreign transfers.

The number of prior transfers of technologies transferred to Canada and western Europe, respectively, during the 1949–78 period are reported in Table 6-8. The data are on new product technologies and relate to arm's-length and internal transfers by U.S.– based multinationals. As the table indicates, Canada stood relatively high in the transfer order compared with western Europe until 1960. Since that time, however, the two have been on a virtually equal footing.

These data also hint at something else. The number of prior transfers associated with the average transfer to either Canada or western Europe has increased markedly since 1965. This is one indication of the compression of the diffusion process or what Vernon (1977) calls the compression of the product cycle.

Mansfield (1985) also documents the existence of this phenomenon. Elsewhere, Mansfield (1984) details the manner in which the product cycle has in fact been compressed. As far as new product technologies are concerned, he finds that the traditional pattern of exporting the product initially and subsequently exporting the underlying technology to affiliates or licensees no longer existed by the mid-1970s:

> Based on our data, the "export state" of the product cycle has often been truncated and sometimes eliminated. Particularly for new products, firms frequently begin overseas production within one year of first U.S. introduction. (p. 137)

TABLE 6-8 Average Transfer Order, New Product Transfers to Canada and Western Europe, 1949–78

	Canada		Western Europe	
	Total Transfers	Average Number of Prior Transfers[a]	Total Transfers	Average Number of Prior Transfers
1949–52	5	1.4	21	2.8
1953–56	17	1.5	21	3.4
1957–60	23	1.9	50	3.1
1961–64	45	2.1	115	2.9
1965–68	32	2.8	142	2.6
1969–73	27	3.1	76	3.3
1974–78	13	4.9	93	5.1

Source: Estimates made by the authors using the Multinational Enterprises Database.
a. A value of 1 would imply one prior foreign transfer, etc.

This finding does not extend to new process technologies, which tend not to be transferred either to affiliates or licensees but rather are embodied in exports of goods and services during the early years of their existence.

The existence of a product cycle implies a positive relationship between the age of a technology and the number of times it has been transferred. The compression of the product cycle or diffusion process implies that the number of prior transfers of a technology of a given age has increased over time, especially since 1965.

We have been able to confirm both the relationship between age and prior transfers and its change over time, using the multinational enterprises database.[10] Our statistical results are reported in Table 6-9. They imply that the relationship between age and prior transfers has rotated upward over time for both Canada and western Europe since 1965.

We also examine statistically the behaviour of the average transfer lag to Canada, using the Economic Council database.[11] The Council did not collect data on prior transfers, so instead we must examine the relationship between the age of a technology at the time of transfer and the year in which the transfer occurred. We also examine the trend of imitation lags over time.

Our statistical results imply that neither transfer lags nor imitation lags declined over the 1960–79 period.[12] These results, taken in conjunction with our findings on the relationship between age and prior transfers, imply that while the age of new technologies entering has remained unchanged, Canada's position in the transfer order has slipped. Given its privileged status with respect to U.S. technologies in the postwar

TABLE 6-9 Estimates of the Relationship Between Age and Prior Transfers

Coefficient (t-ratio)	$\ln PT_{ij} = \ln a_0 + a_1 \ln A_{ij} + a_2 t$ Canada	Western Europe
$(\ln)a_0$	0.051	0.166
a_1	0.235	0.352
	(3.96)	(9.49)
a_2	0.061	0.017
	(4.11)	(2.22)
R^2	0.16	0.18
n	163	528

Source: Estimates by the authors.
Notes: t = statistics in parentheses. t = 0 for transfers made between 1949 and 1964, t = the year of transfer between 1965 and 1978 (1965 = 1).
PT_{ij} = prior transfers of the ith technology at the time of the jth transfer.
A_{ij} = age of the ith technology at the time of the jth transfer.

period, Canada's position could hardly do other than deteriorate as a consequence of both the compression of the product cycle and the increase in the extent to which technologies diffuse internationally. This is apparently what has happened.

National Characteristics and Policies and International Diffusion Lags

Early adoption of new technologies is a means to an end rather than an end in itself. The end is efficient resource use and it must be conceded, indeed emphasized, that resources can be wasted in the premature adoption of new technologies just as easily as they can be wasted elsewhere. Moreover, early adoption does not necessarily imply that a technology will also be fully diffused earlier domestically. Indeed, Nasbeth and Ray (1974, pp.18–19) and Swann (1973) have both noted that domestic diffusion rates are generally faster in the countries that adopt late.

Many of the determinants of the speed of adoption should be regarded as exogenous from a public policy point of view. This would include factor endowments — labour-saving innovations are adopted less quickly in lower-wage countries (Nasbeth and Ray, 1974, p. 305) — and industry mix — the early appearance of numerically controlled machine tools in Britain and the United States has been attributed to the relative importance of the aircraft industries in these two countries (Nasbeth and Ray, 1974, p. 309).

Other factors are clearly amenable to and legitimate concerns of public policy. These would include market size (openness to trade), market structure, capital flows (openness to foreign investment), and information (information gathering and dissemination, including education).

Market size will matter for innovations which involve significant minimum scales of output or significant "set-up" costs. Daly and Globerman (1976, p. 95) argue that Canada's small, tariff-protected market has retarded both the initial adoption and the domestic diffusion of scale-oriented innovations.

Nasbeth and Ray (1974, p. 312) assign a significant role to the openness of the economy itself in encouraging early adoption:

> In the United Kingdom after the war, there was room for quite a few small and medium sized firms which did not maximize profits in the neoclassical sense — competition from abroad was not keen enough to weed them out. In Sweden, with among other things lower tariff barriers, this was not so. Out of a random sample of new processes introduced since the war, Sweden, being a small country,would not be expected to be the innovator of more

than a few. But it appears that a new process, once started in another country, spreads quickly in Sweden if experience seems promising; the relatively large foreign trade and heavy foreign competition together with the close contacts between Swedish firms (in associations and research work) lead to the rapid introduction of new technology.

Swann (1974, p. 64) comes to the same conclusion. Mansfield et. al. (1982) investigate the influence of domestic market concentration on national imitation lags. They find a positive relationship between the two variables in the pharmaceuticals industry, a negative relationship in the plastics industry, and no relationship in semiconductors (p. 35).

The relatively short transfer lags associated with intra-corporate transfers have been documented above. They have also been documented in a multivariate context for Canada by McMullen (1982). The source of this finding lies in a characteristic of the multinational enterprise. It is the efficient institutional form within which to transfer new, radical and relatively untried technologies (Davidson and McFetridge, 1984). The implication of this is that restrictions on multinationals by host governments can have the effect of deterring or at least postponing the transfer of the most sophisticated technologies to the host country. In the simplest terms, if the intra-corporate mode is cut off, it may be a long time before the arm's-length alternative is sufficiently profitable to justify the transfer.

This reasoning implies that, other things being equal, diffusion lags should be greater in the cases of countries which screen foreign investment or maintain equity controls. We conducted TOBIT analysis of the determinants of the order in which a country receives a specific technology and found that, given national, social, economic and demographic characteristics, countries which screen foreign investment extensively and/or maintain equity controls have a lower position in the transfer order.[13]

In sum, there is at least some evidence to the effect that policies favouring free capital flows (at least in technologically oriented industries) reduce international diffusion lags. Information is also important. The relationship between education and intra-industry diffusion rates is discussed above. The role of government in supporting and participating in information gathering and dissemination arrangements is discussed below.

Insofar as the evidence on international diffusion is concerned, both Mansfield (1985) and McMullen (1982) emphasize the association of domestic R&D expenditures with shorter transfer lags. This may reflect, in part, the role of R&D in making firms aware of the potential of technologies available abroad.

Inter-Industry Diffusion

The previous section focusses attention on the rate at which a specific innovation is diffused within an industry and on the factors which determine that rate. In this section, we are concerned not so much with the rate of diffusion as with the pattern. We wish to describe the pattern of the flow of new technologies from their sources to their users. Are the sources of an industry's technology primarily within the industry? If they are not, do the technologies flow from customers or suppliers (vertical flows) or from unrelated industries (horizontal flows)?

An understanding of the pattern of technology flows is important for a number of reasons. A government cannot assist the innovation process without understanding it. If most of the process improvements in industry A have been the result of R&D embodied in machinery acquired from industry B, the best way to increase productivity in A may be to assist R&D in B.

Similarly, direct intervention in the diffusion process presupposes a knowledge of the source of the new technologies which client firms might apply. If, for example, a firm's customers provide most of the ideas for product improvements, then they would presumably have a central role in guiding a diffusion program.

Finally, there has been much dispute over what constitutes a "high-tech" industry. Clearly, there can be two definitions of "high-tech" — an industry that engages in a great deal of R&D or an industry that is a disproportionate user of goods and services with a high R&D content. The industries which qualify as "high-tech" may differ depending on the definition used. We defer for now the question of which definition, if either, has a role to play in public policy formation.

Rosenberg (1982, pp.70–80) describes the complexity and subtle nature of inter-industry technology flows. At one extreme, the mere observation of a new technique being employed in one industry may inspire a number of similar or possibly quite different applications in other sectors.

More tangibly, innovations may be a consequence of suggestions made by suppliers or customers in other industries. Often the suggestions of customers are embodied in new models of an existing product. The cumulative effect of these changes may affect performance characteristics profoundly while leaving the outward appearance of the product unchanged.

Rosenberg calls this "learning by using" and cites the example of the DC-8:

> In this aircraft, operating energy costs over its life span on a per-seat mile basis have been reduced 50 per cent even though the basic configuration has remained largely unchanged and the modifications have been relatively unsophisticated compared to differences between aircraft types. Clearly an

> important set of modifications involves the engines. . . . At the same time modifications of the wing profile have reduced the drag of the aircraft. . . . Engine pylon design also underwent some modification. These variations in the aircraft's geometry were motivated by the drag reduction and increased fuel economy they were able to provide. (p. 127)

The role of the customer, the airline in this case, is central:

> In the case of embodied learning, the role of final product users (airlines) is very important in product differentiation and modification. . . . As a result of the actual use of the aircraft, learning also takes place concerning design aspects and many factors that affect the operating costs of a new model airplane. (p. 125)

While the flow of technology from industry to industry can take the form of ideas and suggestions, most investigators have focussed their attention on technological changes which are embodied in the goods and services purchased by one industry from another. Technological improvements embodied in capital goods such as textile machinery, electric power generation equipment, or pulp and paper machinery have been the basis for much of the increase in productivity observed in the textile, electric utility, and pulp and paper industries. Improvements in intermediate inputs such as fabrics have facilitated substantial product innovation in the clothing industry. New intermediate inputs such as plastics and aluminum have replaced steel in automobile and other production. Fibre optics are replacing copper in telecommunications. The list is endless.[14]

There are a number of approaches to the measurement of interindustry technology flows. The first concentrates on the flow of ideas, suggestions and know-how. The measurement technique is a sample survey of innovating firms wherein the latter are asked the source of either the idea or the technology underlying innovations they have introduced. This is the approach used by De Melto et al. (1980) for Canada, by de Bresson and Townsend (1978) and Pavitt (1983) for Britain, and by Allen et al. (1983) for Ireland, Mexico and Spain.

Of the 283 innovations studied by De Melto et al., in 96 cases at least some of the technology came from outside the innovating firm. The technology came from the parent firm in 55 percent of these cases, from a supplier or customer in 19 percent, from a consultant in 11 percent, and from an unaffiliated joint venture partner in 9 percent of the cases. The remaining sources were unspecified.

Allen et al. find that the ideas for innovations came from a firm in the same industry in 23 percent of the cases, from a supplier or customer in 35 percent of the cases, from trade fairs and trade or other publications in 22 percent of the cases, and from firms in other (not vertically related) industries in only 2 percent of the cases.

Pavitt's survey covered 2000 technical innovations introduced in Britain between 1945 and 1979. Pavitt notes but does not quantify the flow of innovations from the manufacturing sector to other sectors. The most important flows were from the chemical industry to agriculture, from the machinery industry to mining and construction, from motor vehicles to transportation and government, from electronics to transportation and government, from instruments to mining, medical services and government, and from pharmaceuticals to medical services.

Pavitt calculates the ratio of innovations produced to innovations used for individual manufacturing industries. The ratio of production to use ranges from 0.23 in the textile industry to 7.86 in the machine tools industry. Thus, the latter produced eight times as many innovations as it used. Other big technology exporters are the pharmaceuticals and the instruments industries (p. 121).

De Bresson and Townsend, also using British survey data, construct an input-output table showing innovation sources and users (p. 51). Unfortunately, their industry grouping (including performance maximizing, cost minimizing and sales maximizing sectors) is not very useful from the standpoint of interpreting the innovation input-output coefficients they report. They do, however, confirm Pavitt's finding that innovations originate in relatively few sectors but are applied rather more widely.

In sum, the survey evidence emphasizes the importance of competitors, suppliers and customers as sources of ideas and disembodied technology. It also shows that relatively few industries provide most of the embodied new technology. This finding is confirmed by the other measures of inter-industry technology flows, to which we now turn.

A second approach to the measurement of inter-industry technology flows employs R&D intensity (R&D as a proportion of gross output) as a measure. The amount of technology produced within an industry is assumed to be proportional to its own or direct R&D intensity. The amount of technology flowing in from other industries is assumed to be proportional to an industry's indirect R&D intensity. The indirect R&D intensity of an industry is simply a weighted average of the R&D intensities of the other industries in the economy. The problem is to determine the appropriate weights. Two methods have been used.

The first is to use input-output weights. This method has been used by Hartwick and Ewen (1983) and Postner and Wesa (1983) in Canada, and by Griliches and Lichtenberg (1984) among others in the United States. It assumes that the benefits derived by industry A from R&D conducted by industries B and C are proportional to the (constant dollar) purchases of industry A from industries B and C. The R&D efforts of industries B and C thus flow through to A in the form of materials, services and capital goods sold by B and C to A.

A second set of weights have been derived from patent data by Scherer (1982a, 1984) in the United States. Ellis (1981) notes that a similar set of weights could be derived from Canadian patent data. Scherer derives his weights by having a sample of 15,112 U.S. patents coded by engineering and chemistry students to their industry of origin (the industry in which the invention occurred) and the industries in which use was anticipated.

Canadian patents are routinely coded by patent examiners to industry of manufacture and industry of use. Industry of manufacture is the industry which is most likely to manufacture a patented product. It is not necessarily the industry in which this product was invented. For this reason the approach used by Scherer could not be duplicated at present with Canadian data.

A final approach to the measurement of inter-industry technology flows makes use of what we might call indirect patents, as opposed to indirect R&D. This approach has been taken by Seguin-Dulude (1982). The latter takes as her measure of the flow of technology from industry j to industry i the number of patents (issued in 1978) for which j is the industry of manufacture and i is the industry of use. The within-industry flow of technology (for the ith industry) is the number of patents for which the ith industry is both the industry of manufacture and the industry of use. Scherer refers to this intra-industry flow as process innovations. The Canadian data report process patents separately.

To summarize, inter-industry technology flows can be measured as flows of information, as flows of innovations from source to using industries, or as imputed R&D or patent flows. In the case of imputed R&D flows, the relative importance of any source industry to any using industry may be approximated with either intermediate input or patent-based weights.

Having described the measurement efforts of various investigators, we must now assess their implications. Three questions arise. First, what do these inter-industry technology flow measures tell us? Second, are they in broad agreement? Third, in what sense, if any, can one be regarded as superior to the others?

These measures tell us, first, that the sources of innovation are concentrated in a few industries while use is much less concentrated. For example, four industries (machinery, electrical products, chemicals and other manufacturing) were the industry of manufacture in 80 percent of the patents issued in 1978. The four largest users (machinery, transportation equipment, electrical products and chemicals) accounted for 49 percent of the use.

All studies agree on the concentration of the sources of technology. They are also in broad but far from perfect agreement regarding the relative degree of dependence of various industries on external sources of technology (indirect R&D). The findings of four studies on this matter

(technology produced by the *i*th industry as a proportion of the technology produced and used by the *i*th industry) are reported in Tables 6-10, 6-11, 6-12 and 6-13.

In general, the industries providing the greatest fraction of their technological requirements are electrical products, machinery, chemicals and miscellaneous manufacturing. The industries providing the least are construction, agriculture, forestry and fishing, and, in manufacturing, leather, food and beverages, and textiles.

The Seguin-Dulude and Scherer (U.S. patent weights on R&D expenditures) approaches produce very similar rankings of the degree of dependence on externally generated technologies. Neither matches the Hartwick-Ewen (input-output weights on R&D to gross output) measure or ranking very closely, although there is a statistically significant positive correlation between the Ewen-Hartwick and the Seguin-Dulude and Scherer measures respectively. The poorest match is between Pavitt's (innovation survey) and Hartwick-Ewen's rankings. Even here, the correlation is statistically significant.

The differences in the rankings relate as much to differences in operating assumptions, such as those made about the industries to which R&D expenditures are to be allocated, as they do to differences in the methods themselves. For example, the relative importance of within-industry R&D in the communications (service) and the communications equipment (manufacturing) industries would depend on the distribution of the R&D expenditures of Bell-Northern Research between these two industries. Under the Canadian patent (Seguin-Dulude) approach, the communications (service) industry cannot be an industry of manufacture and is therefore the source of none of its technology, unless process patents are attributed to it.

More fundamentally, the patent-based and input-output–based weighting schemes differ with respect to their treatment of capital goods. Patent weights treat a new machine the same as a new material input such as a fabric. Input-output tables do not report inter-industry flows of capital goods. The latter show up as "final demand" on the output side and as "depreciation" on the input side. Postner and Wesa (1983, Appendix B) create their own input-output matrix of capital goods flows. Hartwick and Ewen do not include capital goods flows in their analysis.

Patent-based measures will, of course, overweigh the importance of industries in which technology is patentable relative to those in which it is not or in which patenting is eschewed in favour of the common law protection to accorded know-how. Similarly, many technological improvements take place outside the ambit of formal R&D. All measures examined here are subject to distortions arising from these sources, unless the flows of know-how and informal R&D are proportional to patent and formal R&D flows.

TABLE 6-10 Alternative Measures of Technological Self-Sufficiency

	Hartwick and Ewen		Scherer		Seguin-Dulude			
					With Process		Without Process	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank
Food, beverage and tobacco	0.2563	16	0.6449	10	0.3634	11	0.1679	12
Rubber, plastics	0.3054	15	0.6112	12	0.3298	13	0.1245	13
Leather, textiles and knitting mills and clothing	0.3116	14	0.5206	15	0.3261	14	0.1910	11
Wood and furniture fixtures	0.3135	13	0.5485	14	0.3435	12	0.2066	10
Paper and allied products	0.4448	8	0.6285	11	0.2519	15	0.0545	16
Printing and Publishing	0.4464	7	0.3695	16	0.1613	16	0.0602	15
Primary metals (including iron and steel)	0.4010	9	0.5686	13	0.4199	10	0.1077	14
Metal fabricating	0.3762	11	0.7949	6	0.4789	8	0.3662	8
Machinery	0.4670	5	0.8740	4	0.6722	5	0.6679	4
Transport equipment	0.6055	4	0.7926	7	0.6921	4	0.6901	3
Communications equipment	0.9072	1	0.9767	1	0.8784	2	0.8718	2
Electrical products	0.7360	2	0.9251	2	0.5073	6	0.4678	5
Non-metallic mineral products	0.3553	12	0.7841	8	0.4943	7	0.3196	9
Petroleum and coal	0.3777	10	0.6742	9	0.7448	3	0.3900	6
Chemical products	0.6708	3	0.8343	3	0.9128	1	0.8492	1
Miscellaneous	0.4472	6	0.8711	5	0.4570	9	0.3692	7

Source: J. Hartwick and B. Ewen, "On Gross and Net Measures of Sectoral R&D Intensity for the Canadian Economy," (Kingston: Queen's University, 1983), mimeographed, p. 20, Table 1; F.M. Scherer, "Interindustry Technology Flows in the United States," *Research Policy* (August 1982): 222–41, Table 2; and L. Seguin-Dulude, "Les flux technologiques interindustriels : une analyse exploratoire du potentiel canadien," *L'actualité économique* 58 (1982): 278–79.

TABLE 6-11 Alternative Measures of Self-Sufficiency

	Hartwick and Ewen		Scherer		Seguin-Dulude				Pavitt	
					With Process		Without Process			
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank
Food, beverage and tobacco	0.2563	8	0.6449	6	0.3634	6	0.1679	7	0.4898	7
Pharmaceuticals					0.3871	—	0.1798		0.8632	—
Textiles	0.3511	7	0.5943	8	0.3261	7	0.1910	6	0.1870	8
Paper and allied products	0.4448	5	0.6285	7	0.2519	8	0.0545	8	0.4595	6
Iron and steel					0.3745		0.1353		0.4764	
Non-ferrous metals	0.3553	6	0.7841	5	0.4943	5	0.3196	5	0.6610	5
Machinery	0.4670	4	0.8740	2	0.6722	3	0.6679	3	0.8871	1
Electrical products	0.7360	1	0.9251	1	0.5073	4	0.4678	4	0.6516	4
Chemical products	0.6708	2	0.8343	3	0.9128	1	0.8492	1	0.7512	3
Other transportation equipment	0.6055	3	0.7926	4	0.6921	2	0.6901	2	0.7561	1

Source: J. Hartwick and B. Ewen, "On Gross and Net Measures of Sectoral R&D Intensity for the Canadian Economy," (Kingston: Queen's University, 1983), mimeographed, p. 20, Table 1; F.M. Scherer, "Interindustry Technology Flows in the United States," *Research Policy* (August 1982): 222–41, Table 2; L. Seguin-Dulude, "Les flux technologiques interindustriels : une analyse exploratoire du potentiel canadien," *L'actualité économique* 58 (1982): 278–79; and K. Pavitt, "Characteristics of Innovation Activities in British Industry," *Omega* (1983), p. 121, Table 7.

TABLE 6-12 Alternative Measures of Technological Self-Sufficiency in Non-Manufacturing Industries

	Hartwick and Ewen		Scherer		Seguin-Dulude			
					With Process		Without Process	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank
Agriculture, forestry and fishing	0.0385	2	0.1857	2	0.0587	2	0.0	—
Mining	0.6591	1	0.3498	1	0.3627	1	0.0	—
Construction	0.0133	3	0.1121	3	0.0273	3	0.0064	—
Transportation	0.1944	—	0.0229	—	—	—	—	—
Others	0.0373	—	—	—	0.0631	0	0.0	—

Source: J. Hartwick and B. Ewen, "On Gross and Net Measures of Sectoral and R&D Intensity for the Canadian Economy," (Kingston: Queen's University, 1983), mimeographed, p. 20, Table 1; F.M. Scherer, "Interindustry Technology Flows in the United States," *Research Policy* (August 1982): 222–41, Table 2; and L. Seguin-Dulude, "Les flux technologiques interindustriels : une analyse exploratoire du potentiel canadien," *L'actualité économique* 58 (1982): 278–79.

TABLE 6-13 The Correlation Between Alternative Measures of Technological Self-Sufficiency

	Manufacturing: Three Measures, 16 Observations		
	Hartwick and Ewen	Scherer	Seguin-Dulude (without process)
Hartwick and Ewen	1	0.66	0.77
Scherer	0.66	1	0.80
Seguin-Dulude (without process)	0.77	0.80	1

	Manufacturing: Four Measures, 8 Observations			
	Hartwick and Ewen	Scherer	Seguin-Dulude (without process)	Pavitt
Hartwick and Ewen	1	0.74	0.69	0.51
Scherer	0.77	1	0.77	0.84
Seguin-Dulude (without process)	0.69	—	1	0.79
Pavitt	0.51	0.84	0.79	1

Source: J. Hartwick and B. Ewen, "On Gross and Net Measures of Sectoral R&D Intensity for the Canadian Economy," (Kingston: Queen's University, 1983), mimeographed, p. 20, Table 1; F.M. Scherer, "Interindustry Technology flows in the United States," *Research Policy* (August 1982) 222–41, Table 2; L. Seguin-Dulude, "Les flux technologiques interindustriels : une analyse exploratoire du potentiel canadien," *L'actualité économique* 58 (1982): 278–79; and K. Pavitt, "Characteristics of Innovation Activities in British Industry," *Omega* (1983), p. 121, Table 7.

Among the improvements which could be made in any of these methods would be the attribution of government R&D (i.e., in forestry or agriculture) to the industry to which it applies. This would raise the "within-industry" R&D component of these otherwise technologically dependent sectors.

Descriptions of the complete pattern of inter-industry technology flows are provided by the source and use matrices reported by Scherer (1982a, Table 2) and Seguin-Dulude (1982, Annex B) and are not reproduced here. We provide the distribution of technology sources for the agriculture sector as an illustration. Scherer calculates that in 1974, the U.S. agriculture sector used $562 million in R&D. Of this, 29 percent came from farm machinery, 25 percent from agricultural chemicals, 14 percent from motor vehicles, and 6 percent from pharmaceuticals. Seguin-Dulude's matrix reveals that of 392 1978 patents for which agriculture was the industry of use, 50 percent listed the machinery industry as the industry of manufacture, 18 percent listed the chemical industry, 7 percent pharmaceuticals, 6 percent food and beverage, and 6 percent were pure process patents.

The next issue is whether industry rankings of technological intensity differ when either indirect R&D or indirect patents are taken into account. The answer to this turns out to be an unequivocal no. The reason is that the industries which are the major sources of technology are also the major users of it. R&D-intensive industries tend to buy R&D-intensive inputs. The most important destination of new technologies is not the non-technological using industries but the "high-tech" source industries.[15] All measures are in agreement on this matter.

The final issue upon which these measures of inter-industry technology flows have a bearing is the existence of inter-industry technology spillovers. The implications of spillovers, their magnitude, and relationship with diffusion are discussed in a later section.

Before leaving the subject of inter-industry diffusion, it is appropriate to comment briefly on the excellent work of Postner and Wesa (1983). Much of their study is taken up with the measurement of direct and indirect productivity growth. Their approach can be explained in terms of an automobile delivered to a consumer. They measure the decline in labour content of that automobile over time. This, simply stated, is the inverse of the growth in labour productivity in all industries contributing to the production and delivery of that automobile. Direct productivity growth is defined as productivity growth in automobile manufacturing itself. Indirect productivity growth includes productivity growth in the steel, rubber, plastics, metal mining, petroleum refining, and other industries representing upstream inputs and in transportation, wholesaling, retailing and other industries representing downstream inputs. Thus, 58 percent of the productivity growth in the industries contributing to the delivery of an automobile occurred within the automobile

manufacturing industry itself over the 1961–76 period. The rest occurred in industries providing either upstream or downstream inputs (p. 16).

The analysis of Postner and Wesa tells us not so much about technological flows as about how technological improvements in various industries combine to reduce the cost of a final good or service consumed by households or government. It serves to remind us that technological improvements need not be diffused to the automobile manufacturing industry in order to benefit the ultimate users of automobiles.

Diffusion from Government to Industry

Commentators on Canadian science policy from the Lamontagne Committee (Senate Special Committee on Science Policy) in 1970 to the Wright Commission (Task Force on Federal Policies and Programs for Technology Development) in 1984, have maintained that too much Canadian R&D is done within the government. The proportion of R&D performed within the government has fallen in recent years but that is not the issue here. The issue is why the performance of R&D within the government rather than in industry makes a difference. One reason could be that the location affects the nature of the projects chosen. The Wright Commission is of the view that government laboratories fail to consult adequately with industry and that consequently the projects they undertake are often commercially irrelevant. The second reason is that while projects with commercial potential may be undertaken, their results are seldom transferred to potential industrial users. This problem, a failure of technology to diffuse from government to industry, is of obvious relevance to this study.

Two major studies of the interaction between industrial firms and Canadian government laboratories have been published. The first, by Cordell and Gilmour (1976), is based on a questionnaire sent to 179 industrial R&D performers in Canada. They found that 44 percent were aware of the current activities of government laboratories in their field of interest. Insofar as individual agencies and departments were concerned, of a subsample of 80 firms, 41 percent were aware of the National Research Council's current activities and an additional 46 percent had made contact with the Council during the preceding five years. The respective percentages for the other agencies or departments were: Energy, Mines and Resources, 13 and 15 percent; Agriculture, 11 and 11 percent; National Defence, 9 and 7 percent; Atomic Energy of Canada, 3 and 2 percent; Department of Communications, 2 and 2 percent. Reasons given for failure to make contact with government labs were, that respondents regarded themselves as being self-sufficient in R&D and, that many respondents maintained only small R&D units which performed routine tasks (1976, pp. 296–297).

Some 19 of the 179 firms surveyed (10.6 percent) had attempted to develop, manufacture and market a product invented in a government laboratory. Of these, none were rated by the authors as being very successful, four were regarded as moderately successful, and four were deemed to have had little or no success. It was not possible to make a judgment in the other eleven cases (p. 307). The general opinion of the firms surveyed was that government laboratories do quality work but that fruitful interaction with them was impeded by: (a) their lack of market orientation; (b) their failure to understand how the commercial world operates; and (c) their lack of a sense of urgency (pp. 321–22).

The second study was conducted jointly by the Department of Communications and the Ministry of State for Science and Technology and was published in 1980. It examines the transfer of eight inventions from DOC labs to industry. Of these, seven are regarded as successful transfers. Success is not defined explicitly but among the successes is a scanning electron microscope which has earned a "worldwide reputation," a low-cost earth (satellite) terminal whose sales have numbered in excess of 100, and Telidon (p. ii). Among the factors associated with success are:

- the development of personal contacts and professional relationships with technology recipients by means of research contracts and personnel exchanges;
- the choice of small to medium-sized high technology companies as recipients;
- an engineering orientation among government science and technology personnel;
- continuity of government science and technology personnel;
- support of senior government management;
- continued availability of government R&D support through to commercialization; and
- government purchase of equipment developed by industry from transferred technology.

The importance of interaction between government and industry personnel involved in science and technology is confirmed in a study by McFetridge and Bhanich Supapol (1984) of R&D funded by Transport Canada. In the opinion of those interviewed by the authors, the success of a transfer requires the involvement of the intended recipient from the outset of the project. Transfers are more likely to fail or simply not take place if potential recipients are confronted with a technology they had no hand in developing.

The role of R&D-related procurement is emphasized in other studies — for example, one by Nelson (1982). He argues that government participation in the development of proprietary technologies (either intramurally

or by contract) should be confined to areas in which it has a large procurement interest.

Finally, the disposition of property rights is important. The right to technologies developed in the government or under contract to it is vested in the Crown. Industrial users generally have the status of non-exclusive licensees. McFetridge and Bhanich Supapol (1984) find that this lack of exclusivity sometimes discourages commercialization by the contractors.

The limited evidence from other countries is that government research and research institutes are not important sources of commercial innovations. Allen et al. (1983) study the sources of the innovations of small manufacturers (fewer than 1000 employees) in five countries. Other firms (especially foreign firms) were the most prominent source of information leading to innovation. As Table 6-14 indicates, government research institutes were of trivial importance, except in the case of Ireland.

TABLE 6-14 Sources of Ideas Leading to Innovations by Small Manufacturers

	Ireland	Spain	Mexico	Brazil	Australia
			(percent)		
Contact with domestic firms	11.4	13.8	11.1	17.6	10.1
Contact with foreign firms	47.9	34.5	22.2	14.7	91.7
Goverment research institutes	14.0	0	0	2.9	2.9
Trade fairs	6.4	17.2	0	2.9	2.9
Publications	9.3	27.6	44.4	8.8	2.5
Other	23.6	6.9	22.2	52.9	0

Source: D. Allen, B. Hyman and D. Pinchney, "Transferring Technology to the Small Manufacturing Firm: A Study of Technology Transfer in Three Countries," *Research Policy* 12 (1983): 199–211.

Evidence for Britain is reported by Pavitt (1983). He finds that the government conducted 26.3 percent of British R&D between 1970 and 1979 but that it was the source of only 8.6 percent of industrial innovations (p. 127). Of course, this funding could reflect a concentration by government labs on more research (universities conducted 14.1 percent of the R&D and were the source of only 1.5 percent of the innovations) or a poor choice of applied research projects or inadequate attention to diffusion.

Diffusion and Public Policy

Government-to-Industry Diffusion

The Lamontagne Committee (Canada, Senate Special Committee on Science Policy, 1972) was among the first to raise the concern that R&D performed by the government was not being effectively exploited — that is, not being diffused to potential users (p. 584).

The federal government responded to this concern in two ways. First, what became known as the "make-or-buy" directive was issued in 1972. It stipulated that all new mission-oriented R&D of federal science-based departments be contracted out to service or industrial sector firms. While Bhanich Supapol and McFetridge (1982) note that the initial response across departments was uneven, with declines in contracting activity by such major players as the departments of Communications and Energy, Mines and Resources, the aggregate evidence reveals that the proportion of government-funded R&D performed by the government finally did begin to decline after 1978 and has declined by almost 10 percent since then (see Table 6-15).

TABLE 6-15 Federally Performed R&D as a Proportion of Federally Funded R&D, 1970–82

Year	Share
	(percent)
1970	63.8
1971	63.2
1972	65.1
1973	65.0
1974	67.0
1975	67.5
1976	67.8
1977	67.2
1978	68.7
1979	66.6
1980	65.6
1981	63.3
1982	63.3

Source: Statistics Canada, *Historical Data Compendium*, prepared for the Royal Commission on the Economic Union and Development Prospects for Canada (Ottawa: Statistics Canada).

The Wright Commission (Canada, 1984b) recommends that this process proceed much further:

> In our view, R&D should only be done in-house when there is a need for secrecy or neutrality or when contracting-out is not cost-effective in the long-run. In-house R&D can also be justified by the need to develop scientific

competence in particular areas or by the need to maintain contacts with the international scientific community. In all other cases we believe the government should attempt gradually to shift the bulk of its research requirements to outside contractors. (p. 31)

The Doody Committee (Canada, Senate Standing Committee on National Finance, 1984) emphasizes the importance of selectivity in the contracting-out process. Recognizing that contracting itself is not a costless activity, the committee recommends:

. . . that the administration of the government's contracting-out policy be examined to ensure that greater emphasis is given to contracting-out where the potential benefits are greatest. (pp. 441–45)

Whether the transfer of government-funded R&D activities to the private sector has or will increase the utilization of the technologies which are developed is another question. The mere transfer of R&D activity to the private sector is clearly not sufficient to ensure commercial utilization. In their recent study of Transport Canada R&D contracts, McFetridge and Bhanich Supapol (1984) find that between 31 percent (project officer survey) and 37 percent (contractor survey) had involved at least some commercialization.[16] Factors bearing on the probability of commercialization included: (a) the property rights regime; (b) the technological contribution required from the contractor; (c) the source of the initiative for the project; and (d) the nature of the R&D. Specifically, commercialization is more likely: (a) if regulation DSS 1036, which vests all rights to project results in the government, is modified or suspended; (b) if the contractor contributes a proprietary technology to the contract; (c) if the contract is the result of an unsolicited proposal; and (d) if the contract is not issued pursuant to a regulatory mandate (pp. 65–67).[17]

The second policy response to concerns about utilization of technologies developed within the government was a program to transfer research projects (in various stages of completion) out of government labs into industrial labs. The program was initiated in 1975 and is administered by the National Research Council (NRC) under the acronym PILP (Program for Industry/Laboratory Projects). As of the 1983–84 fiscal year, PILP was responsible for 138 projects, 64 of which involved the exploitation in industrial labs of technologies developed at NRC. The remaining projects involved technologies developed by other government departments. The Wright Commission assesses PILP as one of two federal R&D support programs which "really work" (p. 9).

Early in 1984, the PILP program also became involved in assisting the transfer to industry of technologies developed in universities. Univer-

sity-industry cooperation in the field of biotechnology also receives assistance under a separate program now administered under PILP (Canada, NRC, 1983–84, pp. 20–21).

Provincial governments have also attempted to increase the commercial utilization of research conducted within their respective jurisdictions. A program is underway in Saskatoon to transfer technology and university laboratories in that city to new or existing firms. Of 100 possible ventures examined so far, five have resulted in the formation of new companies and six have resulted in new product lines at existing companies. The essential feature of the program is the creation of "business plans" for the commercial exploitation of new technologies. A similar program has been suggested for Halifax.[18]

Neither contracting out nor transferring out will result in commercialization if the technology concerned has no commercial potential. The actual commercial potential of government-supported R&D has been the subject of some study and debate, much of which has taken place in the United States.

The historical contribution of defence-oriented R&D to the emergence and/or growth of the U.S. commercial aircraft, semi-conductor, computer, and pharmaceuticals industries has been documented by Nelson (1982), among others. Nelson's conclusion has some relevance for Canada. Put simply, he concludes that R&D related to defence or space should not be justified or administered on the basis of commercial spinoffs. Spinoffs can occur but are less likely to do so if projects are chosen and administered with an eye to commercial benefits (pp. 460–61).

Insofar as potential commercial applications are concerned, Scherer's (1982a) analysis of federal R&D contract-related patents led him to conclude that:

> Most of the technology developed thereby, at least as discerned through our analysis of patent specifications, was specific to defence and space applications — e.g., jet engine ducting applicable only to fighter-type aircraft, radars that operated at military-blocked frequencies. (p. 242)

In terms of R&D expenditures, Scherer concludes that of $6.77 billion in federally originated R&D, $4.8 billion or 71 percent had strictly military or space-related applications with the remaining 29 percent having some non-defence application (p. 243).

The important conclusion for Canadians is that the drive for commercial applicability should not obscure the fact that much government-supported R&D, while socially productive, does not have an obvious commercial application. It is important that this R&D be effectively utilized by whatever agencies are charged with doing so. This should be taken into account when decisions are made as to who should perform R&D.

Intra-Industry Diffusion

Concern with slow rate at which new industrial technologies are adopted by Canadian manufacturing firms can be traced to an influential study by Daly and Globerman (1976). Their argument runs as follows. (a) New technology is embodied in new physical capital such as machinery. (b) This new physical capital is subject to indivisibilities — that is, to minimum scale requirements. (c) This minimum scale requirement renders new capital equipment uneconomic to small producers who do not acquire it and therefore do not avail themselves of the latest technology. (d) Canadian producers are small because they produce solely for the tariff-protected domestic market.

> The evidence from the various case studies cited is consistent in demonstrating slower adoption of capital-embodied innovations in Canada than in several other developed countries. In cases where the innovation was more capital intensive than existing techniques, thus requiring longer product lengths of run for efficient use, slower adoption reflected the impact of the domestic tariff on plant level production conditions. The experience of the carpet industry suggests that the anti-competitive effects of the tariff might retard the adoption of new techniques even when the innovations are less capital intensive than existing techniques. (pp. 97–98).

The authors' argument regarding the influence of firm size on the adoption decision holds for less capital-intensive technologies if the acquisition process itself (feasibility, evaluation, search) entails a significant minimum expenditure. Indeed, the existence of acquisition costs which decline over time is more consistent with what the authors have observed — that is, delayed diffusion — than capital indivisibilities which imply limited or no diffusion.

The villain of the piece is the tariff. It sustains small producers for whom the new technologies are uneconomic and, in the authors' view, it attenuates the "competitive pressure" to reduce costs (p. 95). The remedy is a decrease in tariff protection. The result, which is likely to occur for reasons formalized by Harris and Cox (1983, pp. 63–90), is a decrease in domestic margins and an increase in length of production runs. Barriers to the diffusion of new technologies which had been posed by indivisibilities — and lack of competition are reduced as a consequence.

In a later study, the Economic Council of Canada (1983) also cites as a problem the slow diffusion of new technologies within both the manufacturing and the service industries.

> Our general finding is that new technology diffuses slowly into Canada from other countries. It also diffuses slowly from firm to firm and from region to region within the country. By "new technology" we mean new and improved products, processes and organizational structures. Although there are some exceptions, case studies show that often the process of

> diffusion of technical change into and throughout Canada occurs more slowly than in other developed nations and not only in the manufacturing sector but in the service sector as well. Substantial benefits could be realized if the diffusion process into and throughout Canada were to be speeded up. We find that scope does exist for policies designed to achieve this. (p. 61)

The analysis in the section on international diffusion might lead one to dispute the Economic Council's conclusions regarding the speed of diffusion into Canada from abroad; this issue receives further consideration in the next subsection. The present concern is with the diffusion of new technologies within Canadian service and manufacturing industries and the rationale for the policies recommended by the Economic Council to encourage faster diffusion.

The Economic Council adopts the central conclusions of the Daly and Globerman study (1976), which were that diffusion was being inhibited both by tariff-induced short production runs and technology policies which emphasize the employment of domestic scientists[19] rather than technological progress. This led to the Council's recommendations in favour of further trade liberalization (pp. 131–32) and a general recommendation that federal and provincial policies toward technical change put greater emphasis on the adaptation of new techniques from abroad and their diffusion within Canada (pp. 80–81).

More specific recommendations include, first, an admonition to both the federal and provincial governments to improve the rate of diffusion of best-practice techniques within the public sector. The methods suggested include the provision of information and of incentives for public sector managers in hospitals, schools, and so on, to act on it. Second, the Economic Council recommends that trade associations take on a greater role in the collection and dissemination to their members of new ideas and technologies and that they be assisted in their efforts by the government.

Perhaps in response to the concerns raised by Daly and Globerman and in anticipation of the recommendations of the Economic Council, there appears to have been an increase in the resources devoted by various levels of government to promote diffusion. In 1981, the National Research Council combined its industrial research assistance program (IRAP) and its technical information service, and began to expand the combined program. As of 1984, the field staff of industrial technology advisors totalled 121, of whom 74 were employed by provincial and other research institutes under contract to the NRC (1983–84 *Annual Report*, pp. 18–20). During the 1983–84 fiscal year, 2,540 projects received support and over 37,000 queries from industry were dealt with.

At the same time, the federal government announced the establishment of a series of technology centres, and the Ontario government has done likewise in setting up six technology centres with a total budget of

$100 million over five years for the purpose of providing information to small companies on currently available technologies (Grossman, 1984, p. 41).[20]

Testimony before the Doody Committee (Senate Standing Committee on National Finance) suggested that too many technology centres have been established and that insufficient attention had been paid to the identification of the needs these centres are to meet. This led the committee to conclude that:

> The Committee is concerned about the proliferation of technology centres in Canada supported by federal or provincial governments that may not be meeting identified needs. It recommends that the federal government, as a matter of urgency, examine its policies with respect to the support of technology centres, taking into account provincial government initiatives in this area, with a view to ensuring that the centre it supports clearly meets existing or potential needs of industry. (p. 43)

The committee also heard evidence that there has been a parallel development of both corporate and industry association activities with respect to the diffusion of the latest developments in manufacturing technology (p. 45).

There has been little discussion of the effect of the tax system on diffusion. Machinery and equipment has been eligible for a two-year write-off for tax purposes since 1972 and for a 7 percent investment tax credit since 1978. There does not appear to be a bias against the acquisition of capital-embodied technology, at least when the comparison is with respect to other assets (such as buildings) and labour.

Whether the tax system is biased in favour of indigenous R&D at the expense of diffusion, capital-embodied or otherwise, is another question. Some investigators (McFetridge and Warda, 1983) conclude that the tax system favours direct R&D over R&D embodied in new machinery. Whether the tax system also favours direct over indirect disembodied R&D (the purchase of technology of know-how or its imitation) depends on the definition of R&D for tax purposes.

Purchases of know-how or packages of technology can be expensed but are not eligible for special incentives. Expenditures made on adapting or copying (reverse engineering) would be eligible. This raises the possibility that copying might, in some cases, be inferior on a before-tax basis but superior on an after-tax basis. The result is inefficiency on a national and especially on a global basis. The same result will occur and, according to Daly and Globerman (1976, pp. 75–76), it has occurred, as a consequence of targetting R&D subsidies toward the research end of the R&D spectrum.

As Pavitt (1983, p. 125) notes, the data collected by De Melto et al. (1980) show that the R&D component of imitations is almost as large as

the R&D component of innovations (55 percent versus 62 percent of total cost). Thus, innovations and imitations are accorded roughly the same treatment by the tax system.

The R&D component of innovations based on externally acquired technology amounts to 45 percent of project cost, as opposed to 63 percent for innovations derived from in-house technologies. The confinement of tax incentives to R&D may thus have an effect whether technologies are derived from internal or external sources.

This raises the fundamental question of whether and how much the innovation support system should favour in-house technologies rather than technologies from external sources. This question is dealt with below.

International Diffusion

Early studies of the international diffusion of technology to Canada were concerned with the terms upon which technology was acquired rather than the speed with which it was acquired.[21] This concern with the terms upon which Canada acquired technology from abroad was focussed in two areas. First, it was thought that Canada's intellectual property laws conferred too much market power on foreign patentees at the expense of domestic consumers and licensees. This concern was reflected in the 1969 amendments to the Patent Act, which provided for compulsory licensing of imports of pharmaceuticals at a royalty rate fixed by the commissioner of patents. Prices of patented pharmaceuticals have fallen markedly as a consequence of this measure, combined with substitution rules imposed by provincial drug insurance plans. Compulsory licensing of pharmaceuticals is currently under scrutiny of the Eastman Royal Commission.

Concern regarding the terms on which Canada was able to acquire new technology is also reflected in the recommendations of the Working Paper on Patent Law Review (Canada, 1976). Among its recommendations were: (a) more general compulsory licensing provisions for patents not worked in Canada; (b) introduction of the concept of exhaustion; (c) prohibition of unilateral grantbacks; and (d) prohibition of export restrictions (pp. 144, 166–70). The Working Paper saw compulsory licensing as a tool to effect the transfer of actual technologies to Canada instead of technologies embodied in imported goods.

The concept of exhaustion means simply that a patentee's right should be exhausted once the patented good is sold. That is, the patent should not provide for restrictions on resale. In practical terms, this would allow for the arbitrage of any international price difference which discriminated against Canada. Canadians could purchase at the lowest price charged by the patentee anywhere in the world and import into Canada without infringing the Canadian patent.

A unilateral grantback is the assignment by a licensee of the rights to all technologies developed under license to the licensor. Unilateral grantbacks were thought to prevent Canadian licensees from developing an autonomous technological capability on the basis of technology acquired under license from abroad.

There are two questions about these measures. First, are they productive from a Canadian point of view, as their proponents believe? Second, if they are beneficial from a Canadian but not from a global point of view, should Canada still undertake them?

The effect of compulsory licensing of pharamaceuticals has been to effect an income transfer from foreign patentees to Canadian consumers. There has been no "supply side" effect in Canada because the pharamaceuticals in question are largely imported, whether they are subject to a compulsory license or not. Negative effects on Canada would be indirect and would include the retaliation against Canadian patentees by other jurisdictions and a general deterioration in the system of world intellectual property rights, which would presumably not be in the Canadian interest.

Since a patent would probably be worked in Canada if it were the low-cost production location, a general system of a compulsory licenses to work in Canada would have the effect of replacing a low-cost foreign source of the patented good with a high-cost local source. While a number of outcomes are possible, benefit to Canada is unlikely unless the compulsory license also provides for a concessionary royalty rate. Since in this case Canadian benefits are at the expense of the foreign patentee, the above discussion regarding retaliation again applies.

Grantbacks and export restrictions will normally be the subject of bargaining between the patentee and a potential licensee. The right to export to the markets or to derivative technology can be acquired by the licensee at a price which the latter may or may not find profitable to pay. Prohibition of these terms effectively obliges the licensee to pay for these ancillary rights whether this is the most profitable course of action or not. The implication is that unless patentees are obliged to make rights to derivative technologies and export markets available at concessionary rates, the cost of the prohibition of grantbacks and export restrictions will be borne by domestic licensees. If concessionary rates are extracted, considerations regarding retaliation again apply.

The essential conclusion here is that any benefits to Canada from changes in intellectual property rights come at the expense of foreigners. How far should Canada go in this direction? One answer would be to conform to the practices of the major industrial jurisdictions such as the European Economic Community, Japan or the United States. Many of the changes suggested in the Working Paper might be justified on this basis.

The second focus of concern has been the terms and conditions upon which multinational enterprises transfer technology to Canada. This concern is reflected in a series of studies by the Science Council, beginning with *Innovation in a Cold Climate* (1971) and culminating in *Forging the Links* (1979).

The Science Council (1979) discerns two problems faced by firms wishing to import technology into Canada. First, technology imported by branch plants of foreign multinationals is often tied, in the Science Council's view, in the sense that it can only be used for domestic purposes. As a consequence:

> Possibilities for using imported technology to develop distinctive products within Canada for domestic use and to exploit export markets are therefore lost. (p. 54)

Second:

> Because many indigenous Canadian firms are small and weak they are often not in a position to negotiate effectively with foreign firms to obtain technology on favourable terms. Consequently, Canada has generally been unable to capitalize on many of the opportunities afforded by purchased foreign technology for the creation of an indigenous technological capability. (p. 54)

To improve the terms upon which Canadian firms (branch plant or other) are able to import technology, the Science Council recommends, first, that in return for the right to locate in Canada, multinationals be obliged to make technology purchases in Canada, to make advanced technologies available to Canadian firms on a licensed basis and to take on a Canadian equity interest or joint venture partner (pp. 54–55). Second, world product mandates are to be encouraged. Third, government assistance should be provided to give small Canadian firms the negotiating power to obtain access to technology on favourable terms. Fourth, the government should insist on offsets in the form of local orders and technology transfers in return for defence orders placed abroad (p. 55).

With the exception of government participation in the negotiation of technology acquisitions, the other recommendations have been or were already incorporated, in some fashion, in public policy. The Foreign Investment Review Agency routinely extracts concessions, often involving technology, from investors.[22] The Department of Regional Industrial Expansion has negotiated memoranda of agreement with multinationals, such as Pratt and Whitney and General Electric, which provide for some form of world product mandate. Offset provisions have been part of defence procurement arrangements for years.

Daly and Globerman (1976) were among the first to express concern at the speed at which technology diffused internationally to Canada. They note from their case studies that both the first and subsequent adoptions

tended to be slower in Canada (p. 95). As previously noted, their solution lies in trade liberalization and a reorientation of support policies toward technology acquisition. The Economic Council (1983) also concludes that the rate of diffusion into Canada has been relatively low (p. 61) and recommends further trade liberalization and a greater emphasis on the support of diffusion as opposed to indigenous R&D as a remedy (pp. 61, 80–81).

The Economic Council also sees the potential of the multinational enterprise as a vehicle for the transfer of new, complex technologies to Canada:

> A particular finding of considerable importance is that one of the fastest and most effective channels for the transfer into the country of new, expensive, state-of-the-art technology and new ideas is the multinational corporation. (p. 61)

This leads to the recommendation that the Foreign Investment Review Agency give greater weight to the potential for technological and productivity improvements when assessing foreign investment proposals (p. 83).

Recommendations in support of collective information-gathering activities, discussed in the previous subsection, were presumably intended to reduce the international as well as the domestic diffusion lag.

Freer trade, a less obtrusive scrutiny of technology-oriented multinationals by FIRA, and shift of support from R&D to diffusion are in essence the steps the Economic Council would take.[23] This places it somewhat at odds with the Science Council, which would intervene further in the affairs of the high technology multinationals.

There is a real trade-off here. The intervention recommended by the Science Council would be administratively costly and would delay or eliminate some transfers (noted in the section on international diffusion). On the other hand, it may be that Canada has some bargaining power in some situations and that the transfers which do occur would be on more favourable terms for Canada. Whether there would be a net benefit is difficult to say, but we are inclined to doubt it.

The Economic Council's approach relies on trade liberalization as the vehicle for ensuring that new technologies are exploited by Canadian-based firms in export markets. With trade liberalization, branch plants either enter specialization arrangements, obtain world product mandates, or cease operations. The evidence is that in many but not all cases, one of the first two options is taken. Under these arrangements, the Canadian unit either has access to or participates in the creation of the latest technologies and exploits them in export markets. It is argued that the world product mandate option entails greater externalities (Harris, 1985; Bishop and Crookell, 1983) and for this reason should be encouraged by government. This question is addressed in the next subsection.

The government has recently expanded its efforts in technical information dissemination, as noted above. Suggestions have also been made for a greater government effort in the area of international technological intelligence. The Doody Committee (Standing Senate Committee on National Finance, 1984) recommends that the government review the role of the science counsellors in Canadian missions abroad in technical intelligence-gathering (p. 34). Perhaps coincidentally, the Science Council (1984) recommends that Canada's network of science counsellors (which currently consists of seven counsellors in six countries) be expanded and given more support. The purpose would be to acquire more information regarding industrial technologies, which would then be transmitted back to Canadian firms via the National Research Council and provincial research councils.

Zeman (1984) suggests that private technology brokers, contract research organizations, and long-term technology think tanks are also lacking in this country. In his view, these institutions could also serve a legitimate function in acquiring technology.

Diffusion and Spillovers

As should be abundantly clear by now, the diffusion of technology is simply the transfer from its source to its users. Diffusion may or may not involve spillovers. The latter are defined to occur when the source of technology is not fully compensated by the users. Full compensation does not occur unless the social benefits of an innovation accrue to the innovator.

Government support of innovation is often justified on the basis of spillovers. The greater the spillovers (to domestic users), the greater the amount of support required. The magnitude of spillovers is therefore of interest for policy purposes.

The evidence regarding intra-industry and inter-industry spillovers is summarized in the study by Bernstein in this volume. Our purpose here is simply to show the manner in which the measures of inter-industry diffusion described above have been used to draw inferences regarding the magnitude of spillovers.

The methodology here is to include indirect R&D in a productivity growth model. That is, the growth in the productivity of labour and capital in the *i*th industry is expressed as a function of the R&D conducted by that industry (direct R&D) and other industries (indirect R&D). This has been done in the United States by Scherer (1982a, 1982b, 1984) using patent weights, by Griliches and Lichtenberg (1984) using input-output weights, and by Link (1983) using survey data.[24] In Canada, Hartwick and Ewen (1983) and Postner and Wesa relate labour productivity growth to (input-output weighted) indirect R&D. Hartwick and Ewen find no relationship while Postner and Wesa find a positive relationship.

The interpretation of the relationship between productivity growth and indirect R&D is important. If the R&D expenditures of all input suppliers are fully reflected in the prices they charge (i.e., so that the quality-adjusted price of inputs remains unchanged), there will be no relationship between productivity growth and indirect R&D on an industry basis. Thus a positive relationship between industry productivity growth and indirect R&D could imply that input prices do not fully reflect quality improvements — that is, that some of the benefits of quality improvements spill over into the using sectors.

A positive relationship may also be a consequence of measurement errors. Measured input prices may not properly reflect quality improvements. As a consequence, real input use will be understated and labour or total factor productivity growth overstated. If measurement errors are greater for R&D intensive inputs (which seems reasonable), then a productivity growth–indirect R&D relationship will be observed in the absence of any spillover.

Thus, although studies on technology flows have the potential to tell us a great deal about the magnitude of spillovers and the "victims" and beneficiaries of them, there are some serious measurement problems to be aware of and to overcome.

A promising avenue for future investigation is international spillovers. Mansfield (1984, pp. 140–41) finds, for example, that the rate of productivity growth of U.S. firms is an increasing function of their overseas R&D expenditures. This implies that R&D conducted by foreign affiliates and perhaps supported by foreign governments spills over to the benefit of the U.S. parent. The interesting but unanswered question relates to the distribution of the benefits of affiliate R&D between countries of residence of the affiliates and parents.

Globerman (1979) investigates the spillover effects of foreign-owned firms on their domestic counterparts in the same industry. He finds that labour productivity in domestically owned manufacturing plants in a given industry is an increasing function of the degree of foreign ownership in the industry. He interprets this as supporting the notion that foreign direct investment entails spillover efficiency benefits.

Spillovers are also important in the determination of the appropriate emphasis of public innovation support policies. Daly and Globerman and the Economic Council argue in favour of greater emphasis on the support of the acquisition of new technologies as opposed to indigenous invention. Is there a rationale for supporting diffusion to the same or a greater extent than innovation? Is there a diffusion externality (spillover) and is it greater than the innovation externality? Does this imply a change in the emphasis of current policies?

Before too much is made of this issue, it should be noted that diffusion and indigenous R&D are often complementary. As we have noted, inhouse R&D accounts for some 45 percent of the cost of innovations based

on externally acquired technologies. Others have noted that technology acquisition often involves trading technologies. In order to have something to trade, a firm must do its own original R&D. Finally, R&D may be necessary if a firm is to know what new technology to buy. Empirical support for complementarity comes from Globerman, who finds that the early adopters of the technologies he studied tend to be relatively R&D intensive.

Complementarity notwithstanding, there will be occasions when it is necessary to choose between support of technology acquisition and support of indigenous invention. The choice should be based, at least in part, on the relative externalities or spillovers associated with the two activities.

Harris, in his monograph for this commission (Volume 13 of the research series), argues that the relevant externality is the learning acquired by workers in high technology industries, the benefits of which are captured by them rather than by the firms which employ them. He argues that over time the learning associated with in-house R&D (hence the externality) is greater than that associated with external acquisition:

> The externalities associated with the R&D process would seem to be greater than with the technology transfer process; in particular, the value of the experience and know-how gained by the technical people involved in an indigenous R&D effort should be recognized because these external benefits are much greater, given the equal current cost assumption, policy should favour the R&D as opposed to technology transfer route. (p. 109)

The question of whether there is more or less learning with R&D as opposed to technology transfer is, of course, an empirical one. For that matter, so is Harris's contention that high-tech projects are deterred by the inability of workers and entrepreneurs to agree on the disposition of the benefits of on-the-job learning.

This speculation can be extended by conjecturing that the acquisition of technology by one firm entails a demonstration effect of the kind that careful shoppers and first or early buyers confer on subsequent shoppers. In this event, later adopters would want to encourage the early adopters (and careful shoppers or searchers) and there may be some circumstances under which society would want to do it on their behalf.

There is thus a rationale for collective search (information gathering) and, given free rider problems, for government support of it. The benefits of this subsidized search might be expected to accrue almost entirely to domestic firms. This may not be true of subsidized R&D, which might involve a significant spillover to foreigners.

At the same time, the technology acquisition process offers as many opportunities for strategic behaviour as the innovation process (Reinganum, 1981, 1983).[25] The possibility therefore exists that adoption

or imitation rates, like rates of innovation, can be too fast as well as too slow from a social point of view.

Finally, it should not be assumed that broader or faster diffusion will leave the rate of innovation unchanged. Innovation and diffusion rates are inextricably linked. The diffusion process involves imitation. To the extent that it involves the support of imitation, the support of diffusion reduces the incentive to innovate. It may be argued a reduction in the returns to innovation is borne largely by foreigners. As noted above, however, the burden of attempts to reduce returns to foreign innovators may be shifted back, in one way or another, onto domestic residents.

While the arguments could proceed at length, the ultimate conclusion must be that we do not know the relative magnitudes of the R&D and diffusion spillovers. The spillover rationale can be adduced in support of policies which assist both information gathering and R&D. Our knowledge is not sufficiently precise for us to make recommendations regarding emphasis.

Conclusion

Among the salient features of our findings are, first, that the international diffusion process has been compressed during the last twenty years. The transfer lag to Canada does not differ, on average, from the transfer lag to other industrial countries. What has changed is the number of technology transfers so that instead of being one of three recipients of a technology of a given age, Canada may be one of six.

Second, in a number of cases domestic diffusion has been slower in Canada than in other countries, particularly the United States. Two of the more unambiguous cases, numerically controlled machine tools in the tool and die industry and computers in hospitals, are also among the more illustrative. Information is deemed to be part of the problem. Major hindrances are the small size of firms in the first case and public sector managerial incentives in the second. The information problem is the "easy" one to solve. The problems regarding firm size and lack of appropriate public sector incentives require more fundamental changes in trade policy and in government organization.

Insofar as policies to assist and promote diffusion are concerned, there has been considerable activity since 1980 by all levels of government and by the private sector. There is no evidence of "policy paralysis" as far as programs to assist direct diffusion are concerned. There has been slower recognition of the fundamental forces which bear on the diffusion process, and less policy action has been taken to correct them. The diffusion process is facilitated by the free movement of both goods and equity capital internationally. Trade liberalization and a relaxation of screening procedures on technology-oriented equity flows would appear to be necessary components of any diffusion-promoting policy package.

There may be an allocative efficiency rationale for government participation in the diffusion process. Whether the assistance involved is or should be as large as the assistance to indigenous R&D is a question which is impossible to answer in the abstract. It obviously must be addressed when specific policy measures are proposed. One illustration would be a proposal to make payment of technology royalties eligible for the R&D tax incentives and to finance this either by reducing direct R&D subsidies or by reducing the R&D tax credit rate. One trade-off might be accepted but not the other. Thus, which view to take regarding a simple proposal to tilt in favour of diffusion depends on what type of indigenous R&D support is to be foregone. Our inclination would be to trade the direct R&D subsidies but not the R&D tax credit rate for more favourable tax treatment of technology royalty payments.

As far as the study of the diffusion process itself is concerned, the forces bearing on the diffusion process have been measured crudely if at all.[26] Many policy recommendations have been advanced — and indeed many new policies have been adopted by government — on the basis of evidence which is both selective in its coverage and ambiguous in its interpretation. There has been excessive concern with the speed of diffusion and insufficient concern with its costs and consequences.

Notes

This paper was completed in December 1984 and revised in February 1985. The comments of Steven Globerman and Dennis De Melto are gratefully acknowledged.

1. In the simplest terms, different S-curves trace different paths through the data and imply different diffusion rates.
2. Globerman (1975, p. 43) finds that a change in the "full" diffusion proportion assumed does not alter his results.
3. See, for example, Swann (1974), Lacci, Davies and Smith (1974) and Globerman (1975a). Failure to use weighted least squares would not necessarily change the international rankings of diffusion rates obtained by these authors.
4. Specifically, the type of intervention required to increase the international diffusion rate is likely to differ from the type of intervention required to increase the domestic diffusion rate. The decision about whether to intervene also depends on the nature of the diffusion lag involved (see the section on diffusion and public policy). For the same reason, it is unclear what the implications are of international comparison of the number of robots per employee in manufacturing. In 1982, this was 23.2 in Japan, 15.3 in Sweden, 5.2 in Germany, 3.1 in the United States, and 1.4 in Canada in 1982. For a discussion, see Grossman (1984, p. 17) and the references therein.
5. Globerman does not report the size of firm at which the probability of adoption is maximized. The results (1975b, p. 431) imply that it is maximized either at 13.5 or 73.5 employees. The latter estimate appears the more plausible.
6. We note in passing that Wozniak (1984) could not have estimated his model in the manner he reports, that is, with identical sets of exogenous variables in both the AMS and IMPT equations.
7. A Canadian study of the geographic diffusion of technology has been conducted by Martin et al. (1979). The authors estimate the average adoption lag of each of five regions (Ontario, Quebec, British Columbia, Prairies, Atlantic) for some or all of seven innovations (computers, oxygen furnaces, electric arc furnaces, roof trusses, containers, special presses (paper making) and shopping centres. Average adoption lags vary from 4.9 years (in the Atlantic region excluding basic oxygen which is assigned a 17-year lag by the authors but was not in fact adopted during the sample period) to 1.41 years in Ontario. Although none of the regional mean lags differ significantly from the grand mean and although it is not clear what an efficient distribution of regional diffusion lags might be, the Economic Council (1983, p. 49) regards these findings as cause for concern. More rigorous Canadian evidence can be found in Globerman (1981). The latter finds limited evidence of regional lags in the diffusion of EDP and automation in grocery wholesaling and retailing.
8. Mean adoption lags in the case of NC machine tools were 6.8 years in Canada and 4.6 years in the United States (Mansfield et al., 1977, p. 138). Mansfield et al. find an elasticity of the adoption lag with respect to firm size of −0.67 (p. 139). Canadian firms were 40 percent smaller than U.S. firms. This implies a U.S. adoption lag of 5.8 years if U.S. firms had been as small, on average, as Canadian firms.
9. Two of the most widely cited case studies are Hufbauer's (1966) study of synthetic materials and Tilton's (1971) study of semi-conductors.
10. See Vernon and Davidson (1979) for a description of these data.
11. See De Melto et al. (1980) for a description of these data.
12. Using the Economic Council's sample of innovations based on external technologies and imitations, we estimated a pooled equation:

$$A_i = 18.2 - \underset{(0.21)}{.48T_i} + \underset{(0.06)}{.02T^2_i}\; R^2 = .01,\; n = 133$$

and an equation for imitations only:

$$A_i = 28.3 = \underset{(0.28)}{1.04T_i} + \underset{(0.36)}{.03T^2_i}\; R^2 = .01,\; n = 69$$

where A_i = years since first world use of the technology upon which the *i*th innovation or imitation is based; T_i = year the *i*th imitation or innovation is introduced; and T^2_i = *T*-squared (*t* – values in parenthesis).

13. Data were taken from the Multinational Enterprises databank. Statistically significant findings were that the *i*th country's position in the transfer order of the *j*th technology increases with its per capita GNP, its literacy rate, and an absence of foreign investment screening mechanisms and ownership restrictions. For a country with the sample maximum development characteristics (highest GNP per capita, etc.), the absence of screening and equity controls has the effect of reducing the expected number of prior transfers from 1.5 to 0.5. Details are available from the authors on request.
14. See Rosenberg (1982, pp. 77–80).
15. For manufacturing industries, Hartwick and Ewen (1983, Table IV) find a correlation coefficient of 0.63 between direct and domestic indirect R&D.
16. Commercialization was defined in this study as any sale of technology developed or information obtained under the contract to buyers other than the contracting department.
17. An example of research pursuant to a regulatory mandate would be research supporting aircraft or vessel safety standards.
18. The suggestion was made by Mr. Denzil Doyle during the research seminar on small business sponsored by the Royal Commission on the Economic Union and Development Prospects for Canada, October 15, 1984 in Ottawa.
19. On the domestic scientific employment bias of science policy, see Daly and Globerman (1976, pp. 79–80); for the Economic Council's view on the effect of small scale on diffusion, see Economic Council (1983, p. 55).
20. Ontario maintains technology centres in Ottawa (microelectronics), Peterborough (robotics), Cambridge (CAD/CAM), Sudbury (resource machinery), Chatham (farm machinery and food processing) and St. Catharines (automotive parts).
21. See Palmer and Aiello (1984) for an excellent discussion and further references.
22. To take an example, when Marks and Spencer acquired the Peoples Department Store chain, the former was obliged by the Foreign Investment Review Agency to make the following undertakings, among others: (a) obtain at least 70 percent of St. Michael brand textiles and clothing and at least 40 percent of St. Michael foodstuffs from Canadian suppliers; (b) use Marks and Spencer textile technology and industrial management expertise in the development of Canadian-made St. Michael merchandise; (c) spend at least $100,000 annually through 1980 on Canadian research and development in textile and clothing technology; and (d) promote the export of Canadian-made St. Michael products (Byron, 1978, p. 6).
23. The Doody Committee also took essentially the same position with respect to the effect of freer trade on innovation (Canada, Senate Committee on National Finance, 1984, (p. 33, p. 46).
24. See the section on inter-industry diffusion for an explanation of the various weighting schemes and their relevance.
25. In the simplest terms, there should be no presumption that the technology acquisition will not be influenced by the same desire to pre-empt rivals as is the innovation process. Harris (1985), for example, speaks of "pre-emptive automation" as a strategic weapon.
26. Gold (1981, p. 266) suggests a number of methodological changes which might make future diffusion studies more useful for policy purposes. These include, first, the recognition that a technology and thus the population of potential adopters evolve continually over time. Second, there must be a greater appreciation of the range of firm-specific influences bearing on the adoption discussion. Third, there must be more investigation of the consequences of fast or slow adoption for the firms and industries involved.

Bibliography

Allen, D., B. Hyman, and D. Pinckney. 1983. "Transferring Technology to the Manufacturing Firm: A Study of Technology Transfer in Three Countries." *Research Policy* 12: 199–211.

Aylen, J. 1980. "Innovation in the British Steel Industry." In *Technical Innovation and British Economic Performance*, edited by K. Pavitt. (London: Macmillan).

Baumann, H.G. 1971. "The Diffusion of Technology and International Competitiveness: A Case Study of the Canadian Primary Iron and Steel Industry." Ph.D. dissertation. Department of Economics, Queen's University, Kingston.

Bernstein, J.I. 1985. "Research and Development, Patents, and Grant Tax Policies in Canada." In *Technological Change in Canadian Industries*, volume 3 of the research studies prepared for the Royal Commission on the Economic Union and Development Prospects for Canada. Toronto: University of Toronto Press.

Bhanich Supapol, A., and D.G. McFetridge. 1982. "An Analysis of the Federal Make-or-Buy Policy." Discussion Paper 27. Ottawa: Economic Council of Canada.

Bishop, P., and H. Crookell. 1983. "Specialization and Foreign Investment in Canada." London: University of Western Ontario. School of Business Administration, Mimeographed.

Byron, C.J. 1978. "The Canadian Experience of Marks and Spencer." *Foreign Investment Review* 1 (Summer).

Canada. Department of Consumer and Corporate Affairs. 1976. *Working Paper on Patent Law Revision*. Ottawa: Minister of Supply and Services Canada.

________. Ministry of State for Science and Technology. Department of Communication. 1980. "Technology Transfer by Department of Communications: A Study of Eight Innovations." MOSST/DOC. Ottawa: The Ministry.

________. Senate. Special Committee on Science Policy. 1970. *A Critical Review Past and Present*, vol. 2. Ottawa: Queen's Printer.

________. Senate. Special Committee on Science Policy. 1972. *Targets and Strategies for the Seventies*, vol. 2. Ottawa: Queen's Printer.

________. Senate. Standing Committee on National Finance. 1984a. *Federal Government Support for Technological Advancement: An Overview* (Doody Committee). Ottawa: Minister of Supply and Services Canada.

________. Task Force on Federal Policies and Programs for Technology Development. 1984b. A Report to the Honourable Edward C. Lumley, Minister of State for Science and Technology (Wright Commission). Ottawa: Minister of Supply and Services Canada.

Cordell, A.J., and J.M. Gilmour. 1976. "The Role and Function of Government Laboratories and the Transfer of Technology to the Manufacturing Sector." Science Council of Canada, Background Study 35. Ottawa: Science Council of Canada.

Daly, D.J., and S. Globerman. 1976. *Tariff and Science Policies: Applications of a Model of Nationalism*. Toronto: University of Toronto Press.

Davidson, W.J., and D.G. McFetridge. 1984. "International Technology Transaction and the Theory of the Firm." *Journal of Industrial Economics* (March): 253–64.

Davies, S. 1979. *The Diffusion of Process Innovations*. London: Cambridge University Press.

de Bresson, C., and J. Townsend. 1978. "Notes on the Interindustrial Flow of Technology in Postwar Britain." *Research Policy* 7: 48–60.

De Melto, D.P. 1970. "The Effect of Foreign Competition on the Canadian Primary Steel Industry: 1950–1966." Ph.D. dissertation, McGill University, Montreal.

De Melto, D.P., K. McMullen, and R. Willis. 1980. "Innovation and Technological Change in Five Canadian Industries." Discussion Paper 176. Ottawa: Economic Council of Canada.

Dixon, R. 1980. "Hybrid Corn Revisited." *Econometrica* 48: 1451–62.

Economic Council of Canada. 1983. *The Bottom Line: Technology, Trade and Income Growth*. Ottawa: Minister of Supply and Services Canada.

Ellis, E.D. 1981. "Canadian Patent Data Base: The Philosophy, Construction and Uses of the Canadian Patent Database, PATDAT." *World Patent Information* 3: 13–18.

Gold, B. 1981. "Technological Diffusion in Industry: Research Needs and Shortcomings." *Journal of Industrial Economics* 29 (March): 247–70.

Globerman, S. 1975a. "Technological Diffusion in the Canadian Carpet Industry." *Research Policy* 4 (Spring): 190–206.

________. 1975b. "Technological Diffusion in the Canadian Tool and Die Industry." *Review of Economics and Statistics* 57 (November): 428–34.

________. 1976. "New Technology Adoption in the Canadian Paper Industry." Study prepared for the Economic Council of Canada. Ottawa: Minister of Supply and Services Canada.

________. 1979. "Foreign Direct Investment and 'Spillover' Efficiency Benefits in Canadian Manufacturing Industries." *Canadian Journal of Economics* 12 (February): 42–56.

________. 1981. *The Adoption of Computer Technology in Selected Canadian Service Industries*. Study prepared for the Economic Council of Canada. Ottawa: Minister of Supply and Services Canada.

________. 1984. "The Adoption of Computer Technology by Insurance Companies." Vancouver: Simon Fraser University, School of Business. Mimeographed.

________. 1985. "Formal Education and the Adaptability of Workers and Managers to Technological Charge." In *Labour Markets in Canada*, volume 18 of the research studies prepared for the Royal Commission on the Economic Union and Development Prospects for Canada. Toronto: University of Toronto Press.

Griliches, Z. 1957. "Hybrid Corn: An Exploration in the Economics of Technological Change." *Econometrica* 25: 501–22.

Griliches, Z., and F. Lichtenberg. 1984. "Interindustry Technology Flows and Productivity Growth: A Reexamination." *Review of Economics and Statistics* 66 (May): 324–28.

Grossman, L. 1984. *Economic Transformation: Technological Innovation and Diffusion in Ontario*. Toronto: Queen's Printer.

Hannan, T.H., and J.M. McDowell. 1984. "The Determination of Technological Adoption: The Case of the Banking Forum." *The Rand Journal of Economics* 15 (Autumn): 328–35.

Harris, R.G. 1985. *Trade, Industrial Policy and International Competition*. Volume 13 of the research studies prepared for the Royal Commission on the Economic Union and Development Prospects for Canada. Toronto: University of Toronto Press.

Harris, R.G., with D. Cox. 1983. *Trade, Industrial Policy and Canadian Manufacturing*. Toronto: Ontario Economic Council.

Hartwick, J., and B. Ewen. 1983. "On Gross and Net Measures of Sectoral R&D Intensity for the Canadian Economy." Kingston: Queen's University. Mimeographed.

Hufbauer, G. 1966. *Synthetic Materials and the Theory of International Trade*. Cambridge: Harvard University Press.

Kamien, M.I., and N.L. Schwartz. 1982. *Market Structure and Innovation*. Cambridge: Harvard University Press.

Lacci, L.A., S.W. Davies, and R. Smith. 1974. "Tunnel Kilns in Brick-Making." *The Diffusion of New Industrial Processes*, edited by L. Nabseth and G. Ray. London: Cambridge University Press.

Link, A.N. 1983. "Interim Technology Flows and Productivity Growth." *Economic Letters* 11: 179–84.

Litvak, I., and C.J. Maule. 1985. "The Canadian Aluminum and Steel Industries." In *Technological Change in Canadian Industries*, volume 3 of the research studies prepared for the Royal Commission on the Economic Union and Development Prospects for Canada. Toronto: University of Toronto Press.

Mansfield, E. 1963. "The Speed of Response of Firms to New Techniques." *Quarterly Journal of Economics* (May): 290–311.

————. 1968. *Industrial Research and Technological Innovation*. New York: W.W. Norton.

————. 1984. "R&D Innovation: Some Empricial Findings." In *R&D, Patents and Productivity*, edited by Z. Griliches, pp.127–48. Chicago: University of Chicago Press.

————. 1985. "Technological Change and the International Diffusion of Technology: A Survey." In *Technological Change in Canadian Industry*, volume 3 of the research studies prepared for the Royal Commission on the Economic Union and Development Prospects for Canada. Toronto: University of Toronto Press.

Mansfield, E., F. Husic, J. Rapoport, A. Romeo, E. Villani, and S. Wagner. 1977. *The Production and Application of New Industrial Technology*. New York: W.W. Norton.

Mansfield, E., and A. Romeo. 1980. "Technology Transfer to Overseas Subsidiaries by U.S. Based Firms." *Quarterly Journal of Economics* (December): 737–50.

Mansfield, E., A. Romeo, M. Schwartz, D. Teese, S. Wagner, and P. Brach. 1982. *Technology Transfer, Productivity and Economic Policy*. New York: W.W.Norton.

Martin, F., N. Swan, I. Banks, G. Barker, and R. Beaudry. 1979. *The Interregional Diffusion of Innovations in Canada*. Study prepared for the Economic Council of Canada. Ottawa: Minister of Supply and Services Canada.

————. 1984. "Commercial Benefits Resulting from Transport Canada R&D Contracts: Final Report." Study submitted to Transport Canada, Research and Development Directorate, Ottawa.

McFetridge, D.G., and J. Warda. 1983. *Canadian R&D Incentives: Their Adequacy and Impact*. Toronto: Canadian Tax Foundation.

McMullen, K. 1982. "A Model of Lag Lengths for Innovation Adopted by Canadian Firms." Discussion Paper 216. Ottawa: Economic Council of Canada,

Nasbeth, L., and G. Ray, eds. 1974. *The Diffusion of New Industrial Processes*. London: Cambridge University Press.

National Research Council of Canada. 1984. *Program for Industry/Laboratory Projects*. Ottawa: The Council.

Nelson, R.R. 1982. *Government and Technological Progress*. New York: Pergamon Press.

Olson, M. 1982. *The Rise and Decline of Nations*. New Haven: Yale University Press.

Oster, S. 1982. "The Diffusion of Innovation Among Steel Firms: The Basic Oxygen Furnace." *Bell Journal of Economics* 13 (Spring): 45–56.

Oster, S., and J.M. Quigley. 1977. "Regulatory Barriers to the Diffusion of Innovation: Some Evidence from Building Codes." *Bell Journal of Economics* (Autumn): 361–77.

Palmer, J.P., and R.J. Aiello. 1985. "International Technology Exchange: An Economic Analysis of Legal Proposals." In *The International Legal Environment*, volume 52 of the research studies prepared for the Royal Commission on the Economic Union and Development Prospects for Canada. Toronto: University of Toronto Press.

Pavitt, K. 1983. "Characteristics of Innovation Activities in British Industry." *Omega*: 113–30.

Postner, H.H., and L. Wesa. 1983. *Canadian Productivity Growth: An Alternative (Input-Output) Analysis*. Study prepared for the Economic Council of Canada. Ottawa: Minister of Supply and Services Canada.

Rapoport, J. 1978. "Diffusion of Technological Innovation among Non-Profit Firms: A Case Study of Radioisotopes in U.S. Hospitals." *Journal of Economics and Business* 30 (2): 108–19.

Reinganum, J. 1981. "Market Structure and the Diffusion of New Technology." *Bell Journal of Economics* 12: 618–24.

————. 1983. "Technology Adoption Under Imperfect Information." *Bell Journal of Economics* 12: 57–69.

Romeo, A.A. 1975. "Inter-industry and Inter-firm Differences in the Role of Diffusion of an Innovation." *Review of Economics and Statistics* 57 (August): 311–19.

Rosenberg, N. 1982. *Inside the Black Box Technology and Economics*. London: Cambridge University Press.

Russell, L. 1979. *Technology in Hospitals: Medical Advances and Their Diffusion, Studies in Social Economics*. Washington, D.C.: Brookings Institution.

Scherer, F.M. 1982a. "Interindustry Technology Flows in the United States." *Research Policy* (August): 227–45.

________. 1982b. "Inter-industry Technology Flows and Productivity Growth." *Review of Economics and Statistics* (February): 627–34.

________. 1984. "Using Linked Patent and R&D Data to Measure Interindustry Technology Flows." *R&D, Patents and Productivity*, edited by Z. Griliches, pp. 417–61. Chicago: University of Chicago Press.

Science Council of Canada. 1971. *Innovation in a Cold Climate: The Dilemma of Canadian Manufacturing*. Report No.15. Ottawa: Minister of Supply and Services Canada.

________. 1979. *Forging the Links: A Technology Policy for Canada*. Ottawa: Minister of Supply and Services Canada.

Seguin-Dulude, L. 1982. "Les flux technologiques interindustriels: une analyse exploratoire du potential canadien." *L' Actualite Economique* 58: 259–81.

Statistics Canada. *Historical Data Compendium*, prepared for the Royal Commission on the Economic Union and Development Prospects for Canada. Ottawa: Statistics Canada.

Stoneman, P. 1983. *The Economic Analysis of Technological Change*. London: Oxford University Press.

Swann, P.L. 1974. "The International Diffusion of an Innovation." *Journal of Industrial Economics* 22: 61–69.

Tilton, J. 1971. *International Diffusion of Technology: The Case of Semiconductors*. Washington, D.C.: Brookings Institution.

Vernon, R. 1977. *Storm Over the Multinationals*. Cambridge, Mass.: Harvard University Press.

Vernon, R., and W.H. Davidson. 1979. "Foreign Production of Technology-Intensive Products by U.S.-Based Multinational Enterprises." Working Paper. Boston: Harvard University. Graduate School of Business.

Wozniak, G.D. 1984. "The Adoption of Interrelated Innovations: A Human Capital Approach." *Review of Economics and Statistics* 66 (February): 70–79.

Zeman, Z.P. 1984. "Towards Technology Acquisition Policy: Six National Approaches." Study submitted to the Royal Commission on the Economic Union and Development Prospects for Canada, Ottawa.

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Technological Change in Canadian Industry

DONALD G. McFETRIDGE, Research Coordinator

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